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Bilingual Language Processing and Interference in Bilinguals: Evidence From Eye Tracking and Picture Naming

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Recognition and interference of a nontarget language (Russian) during production in a target language (English) were tested in Russian-English bilinguals using eye movements and picture naming. In Experiment 1, Russian words drew more eye movements and delayed English naming to a greater extent than control nonwords and English translation equivalents. In Experiment 2, Russian words spelled using English-specific letters drew more eye movements than control nonwords and English translation equivalents; however, both Russian words and nonword controls delayed English naming. Results of the two experiments suggest that nontarget-language information is processed during a target-language task. Recognition and production in bilinguals might function within distinct constraints, with recognition sensitive to lexical information (target and nontarget) and production sensitive to phonological information (lexical and nonlexical).

Keywords Bilingualism; Parallel Language Activation; Picture Naming; Eye Tracking; Visual Word Recognition

The ability to produce words from only one language suggests that bilinguals can exercise a certain degree of control over language selection in production. In

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recognition, however, bilinguals' language selection seems to be less controlled. When processing written information in one language, a bilingual contends with information from the other language that also becomes activated. In the present study, two experiments investigated whether written information from a nontarget language is recognized during a target-language task and whether it interferes with target-language production. Eye movements to competitor words yielded a measure of nontarget-language *recognition*. Picture-naming times in the target language yielded a measure of nontarget-language *interference*. Using two different behavioral measures to index recognition and production within the same task might inform models of bilingual word recognition and production, as well as general models of language processing.

Language Processing in Bilinguals

Lexical access in bilinguals is thought to be largely nonselective, both for recognition and production processes. For recognition, numerous studies converge in demonstrating that linguistic input sharing features for the bilingual's two languages activates information for both languages in parallel. For example, eye-tracking technology has been used to demonstrate parallel activation of two languages during bilingual spoken-word recognition (e.g., Ju & Luce, 2004; Marian & Spivey, 2003a, 2003b; Marian, Spivey, & Hirsch, 2003; Weber & Cutler, 2000). When participants are given spoken instructions to move objects around a visual display, their eye movements are largely automatic and reflect the degree to which the names of objects on the display are similar to the spoken word (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Marian and Spivey (2003a) showed that Russian-English bilinguals listening to object names in English made eye movements to objects whose Russian names overlapped at onset with target English names, suggesting that lexical items in both languages were activated simultaneously. Similarly, for production, multiple studies suggest that mapping of the semantic concept onto an output modality (e.g., speech) occurs in parallel for the two languages (e.g., Colomé, 2001; Costa, Miozzo, & Caramazza, 1999; Jared & Kroll, 2001). For instance, Jared and Kroll showed that French letter-to-phoneme rules delayed reading aloud of English words for French-English bilinguals, thereby demonstrating activation of nontarget-language phonology during a target-language production task.

It appears, therefore, that both recognition and production processes in bilinguals proceed in parallel, with information from the nontarget language activated during a target-language task. However, recognition and production tasks might subsume different cognitive processes and might differ in the extent to which the nontarget language influences processing in the target language. For example, visual word recognition is driven by bottom-up processes (e.g., Dijkstra & Van Heuven, 1998, 2002; Van Heuven, 2000) and is seen as largely automatic in highly proficient first and second languages (e.g., Tzelgov, Henig, Sneg, & Baruch, 1996). Moreover, visual word recognition is thought to be fairly unsusceptible to cognitive control; that is, the nontarget language cannot be "deactivated" during a target-language task (e.g., Dijkstra & Van Heuven, 2002). Language production, on the other hand, is driven largely by top-down processes (e.g., Dell & O'Seaghdha, 1992; Levelt, Roelofs, & Meyer, 1999) and is, therefore, less automatic and more susceptible to cognitive control mechanisms; that is, the nontarget language can be "despecified" or "deselected" when preparing a message in the target language (e.g., de Bot, 1992; de Bot & Schreuder, 1993; Green, 1986; Poulisse & Bongaerts, 1994). Given these differences between recognition and production, it is possible to hypothesize that in the same bilingual individual, a nontarget language will be activated to a greater extent at recognition than at production. The main objectives of the current research were (a) to measure nontarget-language *recognition* during target-language production and (b) to measure nontarget-language *interference* with target-language production. Nontarget-language recognition was measured using eye movements to nontarget-language words. Different eye-movement patterns to Russian words versus nonword controls and English translation equivalents were taken as evidence for recognition of Russian input during an English task. Nontarget-language interference was measured using picture-naming times in the target language. Different reaction-time patterns to naming pictures accompanied by Russian words versus nonword controls and English translation equivalents were taken as evidence for interference of Russian words with English naming.

Language Recognition in Bilinguals

In bilinguals, recognition of linguistic information is not language-specific. For instance, during reading in a target language, nontarget-language information can also become activated (e.g., De Groot, Delmaar, & Lupker, 2000; Nas, 1983; Van Heuven, 2000; Van Heuven, Dijkstra, & Grainger, 1998). Nonselective processing of both languages during reading was incorporated into the Bilingual Interactive Activation (BIA+) model of visual word recognition in bilinguals (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, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegel, 2001; Ferrand & Grainger, 1994; Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000) and the connectionist models of reading (e.g., Gottlob, Goldinger, Stone, & Van Orden, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989; Van Orden & Goldinger, 1994). The BIA+ model proposes that lexical access of a visually presented word in a bilingual is nonselective; that is, when a word is presented, orthographic and phonological information regarding that word is activated for both languages.

Orthographic information that contains input characteristics for the target, as well as the nontarget language, can activate both languages in parallel. For instance, Bijeljac-Babic, Biardeau, and Grainger (1997) found that on a lexical decision task, bilingual speakers had slower reaction times to low-frequency stimuli when these were preceded by high-frequency, orthographically-related primes in the other language. In another study that suggested that orthographic information is accessed in parallel for both languages, Van Heuven et al. (1998) demonstrated orthographic neighborhood effects (i.e., the finding that a word with a large number of orthographic neighbors is recognized slower than a word with only a few orthographic neighbors) both *across* and *within* bilinguals' two languages.

Similar to nontarget orthographic information, nontarget phonological information also appears to be activated during target-language processing. For instance, phonological overlap with words from the nontarget Dutch language was found to hinder performance on an English lexical decision task for Dutch-English bilinguals (Dijkstra, Grainger, & Van Heuven, 1999). Similarly, priming a Dutch lexical item with a phonologically similar French word was found to facilitate recognition of the target item for Dutch-French bilinguals (Brysbaert, Van Dyck, & Van de Poel, 1999). Activation of phonological information for the nontarget language has also been substantiated in bilinguals who speak languages with entirely different alphabets, like Hebrew and English. Specifically, translation priming was found to be stronger when the Hebrew prime and the target English word shared phonology but not orthography (Gollan, Forster, & Frost, 1997). The few studies that have explored language processing in monolingual speakers of a language with two partially overlapping alphabets (Feldman & Turvey, 1983; Lukatela, Savic, Gligorijevic, Ognjenovic, & Turvey, 1978) also seem to suggest that phonological information for the nontarget language is automatically activated when reading in the target language.

Language Production in Bilinguals

Theories of language production in bilinguals propose that activation of lexical items spreads in parallel for the two languages from the semantic system downward; that is, if a Spanish-English bilingual prepares to produce the word "dog" in English, its Spanish translation equivalent "perro" will also be activated (e.g., Costa, Caramazza, & Sebastián-Gallés, 2002; Costa, Colomé, & Caramazza, 2002). Parallel processing of languages during production in bilinguals has been demonstrated using word naming, picture naming, and Stroop/Picture-Word Interference (PWI) tasks. For example, in a word-naming study, Jared and Kroll (2001) demonstrated that participants who spoke both French and English appeared to activate their knowledge of French spelling-sound correspondences when naming words in English. In a phoneme monitoring task adapted for production, Colomé (2001) asked Catalan-Spanish bilinguals to decide whether a target phoneme was present in the Catalan picture names and demonstrated that participants found it more difficult to reject phonemes that were present in the Spanish translations of Catalan picture names than those that were not. Similarly, in a picture-naming study, Costa et al. (2002) demonstrated that pictures whose names were Catalan-Spanish cognates were named faster in Spanish than pictures whose names were not cognates. Facilitation of naming when the picture name was a cognate was attributed to phonological activation of nontarget lexical items. Similarity between target-language and nontarget-language phonology served to facilitate picture naming in the target language.

In a series of experiments using the PWI task with Catalan-Spanish bilinguals, Costa et al. (1999) demonstrated that phonologically overlapping Spanish distractor words facilitated performance on a Catalan PWI task. It was suggested that nontarget-language words were processed to the level of output phonology, where they facilitated picture naming in the target language. In a similar study, Hermans, Bongaerts, de Bot, and Schreuder (1998) demonstrated that for Dutch-English bilinguals, Dutch words that were phonologically related to the Dutch translations of the English targets produced interference compared to unrelated distractors. Along the same lines, cross-script homophones (words that were written in the script of one language but were phonologically viable words in another language) interfered with reading of color names during the Stroop task (Tzelgov et al., 1996), suggesting that phonological processing for the nontarget language took place during a target-language task.

In sum, picture naming, word naming, and PWI studies in bilinguals suggest that nontarget-language phonology is activated during target-language production tasks. However, nontarget language is thought to be activated to a greater degree during target-language recognition than during target-language production. This is because fluent bilinguals are highly capable of producing words in the target language only. In cognitive/computational models of language production in bilinguals, control of nontarget-language interference with target-language production is often managed using inhibition mechanisms, with the nontarget language controlled using top-down processes (e.g., Green, 1998; Grosjean, 2001). An elegant solution to the issue of how a bilingual selects words from a target language has been offered by Costa et al. (1999), who suggested that whereas activation of lexical items proceeds in parallel, only lexical items from the target language compete for selection. This solution maintains parallel language activation, but it sets a limit on interactivity during language production at the level of phonological output, where phonological coding of only the lexical items pertaining to the target language takes place.

Distinguishing Recognition and Production Experimentally

To examine both recognition and production components of bilingual language processing within a single task and participant group, the present study utilized a PWI task modified for use with eye tracking. The PWI task lends itself well to examining recognition and production simultaneously, because it incorporates the two processes into a single paradigm. In the PWI task, a written word acts as a distractor and a picture stimulus acts as a target. In the current study, the word recognition component was measured using eye movements to the distractor word, and the picture-naming component was measured using latency of response for naming the target picture. The reasoning was that if recognition is more susceptible to parallel processing than production, Russian-English bilinguals might demonstrate differences between the visual word recognition component of the task (as measured by eye-movement patterns) and the picture-naming component of the task (as measured by reaction-time patterns). Demonstrating differences in recognition and production processes within the same task and within the same group of participants would suggest differences in cognitive mechanisms involved in the two tasks.

The objective of the classic PWI task is to name pictures while ignoring distractor words embedded within the pictures. The PWI task is sensitive to the relationship between the target picture and the distractor word (e.g., Caramazza & Costa, 2000; Schriefers, Meyer, & Levelt, 1990), such as the word's orthographic and phonological similarity to the picture name (e.g., Jescheniak & Schriefers, 2001; Rayner & Springer, 1986). It has been used successfully with bilingual children (e.g., Goodman, Haith, Guttentag, & Rao, 1985) and bilingual adults (e.g., Costa et al., 1999; Ehri & Bouchard, 1980) to show that semantic, orthographic, and phonological information for the non-target language is activated during picture naming in the target language. Traditionally, the PWI task yields a measure of interference. The interference on the PWI task is attributed to postlexical processes, when both the word and the picture name have already been retrieved (e.g., Costa et al., 1999; La Heij & van den Hof, 1995) and is measured as the difference in reaction times to pictures accompanied by an experimental versus a control distractor word. The logic behind the current experiment was that whereas the reaction-time measure might be more indicative of processes at the level of output, eye movements to and from the word prior to naming might be indicative of processing at the level of stimulus input (i.e., prior to retrieval of its meaning). This reasoning was motivated by findings that eye movements observed during reading are often dictated by lexical information pertaining to the written word, such as lexical frequency, and indicate activation of the lexicon (e.g., Altarriba, Kroll, Sholl, & Rayner, 1996; Deutsch, Frost, Pollatsek, & Rayner, 2002; Engbert, Longtin, & Kliegl, 2002; Liu, Inhoff, Ye, & Wu, 2002; Reichle, 1998; Reichle, Rayner, & Pollatsek, 1999; Starr & Rayner, 2001; Wong & Chen, 1999).

Whereas in a regular PWI task a written stimulus is presented inside a picture, in the modified PWI task the written stimulus and the picture were separated, with the picture in one quadrant of the computer screen and the written stimulus in another quadrant of the computer screen (see Figure 1). Separating the written stimulus and the to-be-named color stimulus on the Stroop task has been previously utilized in cognitive psychology experiments in order to test the roles of visual field and spatial attention in color-naming performance. For example, Brown, Gore, and Pearson (1998) presented distractor words and color targets in contralateral versus ipsilateral visual fields in order to test whether words are processed more efficiently in the right visual field/left hemisphere. Distractor words and color targets were also spatially separated in previous Stroop experiments in order to test the so-called "Stroop dilution" effects, where the presence of a neutral word in addition to the distractor word "dilutes" the Stroop interference effect (e.g., Brown, Gore, & Carr, 2002; Brown, Roos-Gilbert, & Carr, 1995), and to test the effect of spatial invariance of the distractor word on congruency effects in a Stroop task (e.g., Morein-Zamir, Henik, & Spitzer-Davidson, 2002). Results of experiments with modified Stroop tasks suggest that spatially separated word distractors can affect color naming, implying that print processing can occur when print is not in the center of the visual

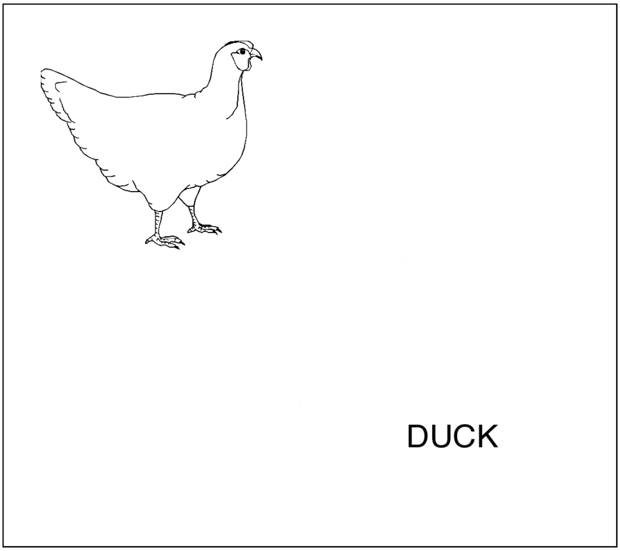


Figure 1 Example of a stimulus in the PWI task modified for use with eye tracking.

field (e.g., Brown et al., 2002). However, spatial separation of a color bar and a written color term can also serve to diminish the Stroop effect (e.g., Brown, et al., 2002 Experiments 1–3; Risko, Stolz, & Besner, 2005). Like other types of contextual information (e.g., participants' expectations [e.g., Tzlegov, Henik, & Berger, 1992] and stimulus characteristics [e.g., Besner & Stolz, 1999]), spatial separation of the color term in relation to the color bar can eliminate the Stroop effect, especially when the spatial location of the distractor word in relation to the color bar is unpredictable (e.g., Risko et al., 2005).

In the current study, the picture stimulus and the distractor word were spatially separated in an attempt to tease apart the processes of distractor word *recognition* and that of distractor word *interference* during picture naming. The location of the distractor word in relation to the picture was randomized, so that it could not be predicted by the participant. The proportion of eye movements to distractor words during the modified PWI task was taken as an indication of the degree to which participants were unable to control their eye movements to the word (i.e., the degree to which letter strings drew the participants' eye movements). Reaction times to naming the target picture stimuli, on the other hand, signified the degree to which written information interfered with picture naming in English. Given prior research showing that unpredictable spatial separation of color terms and color bars eliminated Stroop interference (e.g., Risko et al., 2005), the distractor words in the PWI task modified for use with eye tracking were not expected to interfere with picture naming as a result of automatic word recognition. Piloting the PWI task modified for use with eye tracking in monolingual speakers of English confirmed the absence of PWI effects,[1] suggesting that if reaction-time differences were observed for Russian-English bilinguals, they would not be due to automatic processing of text in either the target or the nontarget language. Instead, reaction-time differences observed for Russian-English bilinguals would be due to allocating attention to distractor words and their subsequent recognition and interference with picture naming in the target language.

The Present Research

Two experiments investigated how Russian-English bilinguals processed written input that contained either orthographic (Experiment 1) or phonological (Experiment 2) information for Russian during an English production task. In order to construct experimental Russian stimuli, the partial overlap between Russian and English alphabets was utilized. The Russian and English languages use different alphabets, with Russian using the Cyrillic alphabet and English using the Roman alphabet. However, 12 letter symbols are shared between the two alphabets (see Figure 2). Six of these symbols map onto similar phonemes for the two languages (e.g., the letter symbol "K" exists in both alphabets and maps onto the phoneme /k/ for both languages). The other six symbols, however, map onto distinct phonemes for the two languages (e.g., the letter symbol "P" exists in both alphabets, but maps onto the sound /p/ in English and the sound /r/ in Russian). For Russian-English bilinguals, then, letter strings might contain symbols common to both alphabets but encode different phonemic entities for the two languages. Moreover, letter strings with symbols specific to one language might contain phonological information for the other language (for instance, the letter symbol "V" does not exist in Russian, but the phoneme that it encodes, /v/, does). Thus, Russian-English bilinguals might be confronted with written information that maps onto both orthographies but is only meaningful for one language. Similarly, Russian-English bilinguals often process written information that might be language-specific in terms of letters but carry linguistic information for another language in terms of phonemes.

In Experiment 1, Russian-English bilinguals were presented with nonword English stimuli that contained letters common to both alphabets; these stimuli, however, were legal words in Russian. When mapped onto their phonological representations using English letter-to-phoneme rules, these letter strings

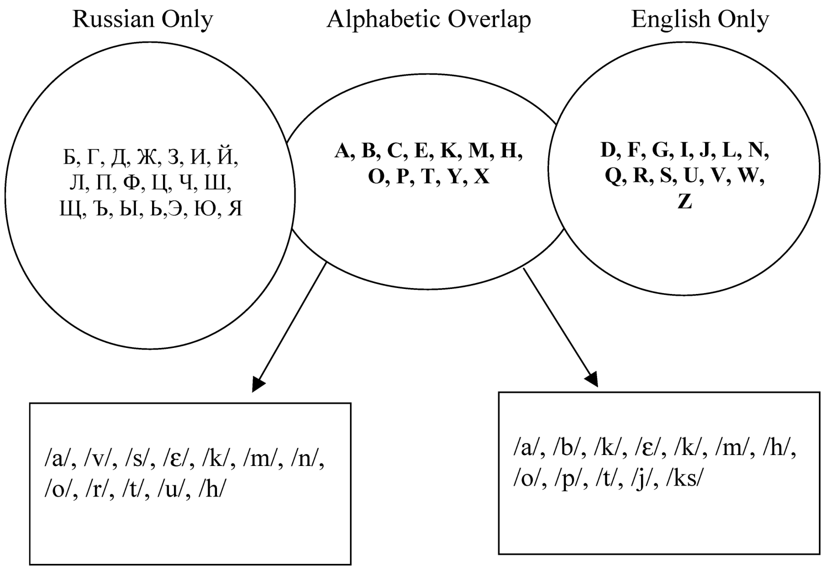


Figure 2 Overlapping symbols in orthographies of Russian and English and the associated phonemes in each language.

remained nonwords in English. However, when mapped onto phonemes using Russian letter-to-phoneme rules, these letter strings constituted viable words in Russian. For instance, the letter string COBA is a nonword in English, both in terms of its letters and in terms of the phonemes the letters map onto – /koba/. In Russian, however, COBA spells out a legal word pronounced as /sava/ and means "owl."

In Experiment 2, Russian-English bilinguals were presented with letter strings that constituted English nonwords containing English-specific letters. These letter strings, however, mapped onto viable Russian words. For instance, the letter string SAVA is a nonsense letter string in English, containing two English-specific letters, S and V, that do not exist in the Russian alphabet. However, when mapped onto its phonological representation using English letter-to-sound conversion rules, /sava/, this letter string constitutes a viable Russian word, "owl."

In sum, Experiment 1 tested whether Russian letter-to-phoneme mappings (derived from nontarget-language orthographic information) influenced processing in the target language. Experiment 2 tested whether English letter-to-phoneme mappings (derived from nontarget-language phonological information) influenced processing in the target language. The two experiments tested the following hypotheses based on previous findings of nontarget-language information (orthographic and phonological) influencing target-language processing (e.g., De Groot et al., 2000; Van Heuven et al., 1998):

1. If nontarget-language orthographic (Experiment 1) or phonological (Experiment 2) information is recognized during a target-language production task, then Russian words in Experiments 1 and 2 would be treated as real words, and eye-movement patterns to Russian words would differ from eye-movement patterns to nonword controls.
2. If nontarget-language information interferes with target-language naming, then Russian words in Experiments 1 and 2 would delay English naming to a greater extent than control nonwords.

Moreover, Experiments 1 and 2 also tested two hypotheses based on previous findings of nontarget-language words and target-language words being processed in a similar manner (e.g., Costa et al., 1999; La Heij & van den Hof, 1995):

3. If nontarget-language information and target-language information were recognized in a similar manner, then Russian words and their English translation equivalents would be treated similarly in terms of eye movements.
4. If nontarget-language information and target-language information interfere with target-language naming in a similar manner, then Russian words and English translation equivalents would delay English naming to the same extent.

Although the word versus nonword comparison (used to index bilingual language processing) underlies many bilingual lexical decision tasks (Nas, 1983), it is different from comparisons usually made in PWI studies. In PWI experiments, picture-naming performance is frequently compared for conditions where the distractor is a semantically related word (in either the target or the nontarget language) versus a semantically unrelated word (in either the target or the nontarget language), and activation of a nontarget language is concluded from similar reaction-time patterns for the target- and nontarget-language semantic distractors. The decision to compare English nonwords that constituted Russian words to English nonwords that did not constitute Russian words was made for two reasons. First, one of the objectives of this research was to examine the word recognition component involved in the task, traditionally measured as the difference in performance on word versus nonword stimuli (i.e., the lexicality effect). Second, because measuring eye movements during the PWI task has not been attempted previously, it was thought prudent to compare a word condition in which interference from the nontarget language has been ubiquitously obtained in prior studies with bilinguals and monolinguals (e.g., Costa et al., 1999; La Heij & van den Hof, 1995; Lupker, 1979; Rayner & Springer, 1986) to a nonword condition where interference is very unlikely to occur (e.g., Rayner & Posnansky, 1978[2]). As stated previously, traditional PWI effects, where a semantically related distractor interferes with picture naming to a larger degree than a semantically unrelated word or nonword, were not tested in these experiments. Instead, these experiments were used to test specific hypotheses regarding detection and recognition of nontarget-language information during a target-language task. Reaction-time differences between Russian words and nonword controls were taken to index the effect of nontarget-language recognition on target-language naming. In this sense, the PWI task in these experiments was used as a framework for examining both recognition and interference of nontarget-language lexical information within a single experimental trial.

Experiment 1: Recognition and Interference of Nontarget-Language Orthography

Recognition and interference of Russian distractor words during an English PWI task was examined. The proportion of eye movements made by Russian-English bilinguals to nonword English stimuli that constituted legal words in Russian (e.g., COBA) was compared to the proportion of eye movements made to nonword bigram-matched control stimuli (FODA) and to English translations of the Russian words (e.g., OWL). Four predictions were made:

1. It was predicted that Russian input would be recognized and would draw a greater proportion of eye movements than nonword controls.
2. It was predicted that recognized Russian words would be processed to the level of phonological lexicon and would interfere with picture naming in the target language to a larger extent than nonword controls.
3. It was predicted that both Russian words and English translation equivalents would be recognized during the English naming task and draw similar proportions of eye movements.
4. It was predicted that Russian words and English translation equivalents would interfere with picture naming in English to the same extent.

Method

Participants

Fifteen Russian-English bilinguals (mean age = 24.5 years, *SD* = 4.73; six females, nine males) participated in this experiment. The participants were born in the former Soviet Union and immigrated to the United States at the average age of 14.56 years ($SD = 5.35$).

Bilinguals' proficiency in the two languages was assessed using both self-reported measures of proficiency and objective measures of reading fluency and reading comprehension. Self-reported proficiency measures of reading, speaking, and understanding were obtained using the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). The LEAP-Q is a comprehensive questionnaire that probes for information pertaining to language acquisition and usage; it has high internal validity, and it appears to be a reliable tool for eliciting thorough self-reported appraisals of language proficiency. The bilingual participants recruited for this experiment reported that, on average, they started to read Russian at 4.84 years of age ($SD = 1.12$) and English at 10.06 years of age ($SD = 4.56$). On a scale from 1 to 5 (with 1 being low proficiency and 5 being high proficiency), bilinguals rated their proficiency of reading Russian as 4.50 ($SD = 0.82$) and proficiency of reading English as 4.56 ($SD = 0.73$). On a scale from 1 to 5 (with 5 being always and 1 being never), they reported being exposed to reading in Russian as 3.06 ($SD = 0.85$) and in English as 4.06 ($SD = 0.77$). When asked to identify percentage preference reading in one or the other of their languages (100% being the total), bilinguals reported 42% ($SD = 34$) preference reading in Russian, 53% ($SD = 4$) preference reading in English, and 5% preference reading in a third language.

Reading comprehension, reading accuracy, and reading speed were assessed by administering a passage-reading task in English and Russian. For this purpose, two passages, one in English and one in Russian, were constructed. The English passage was modeled after a passage used to assess reading comprehension on an SAT test; eight multiple-choice questions designed to assess reading comprehension were also constructed. The Russian passage was constructed to be similar to the English passage, both in subject matter and in style. It was based on a passage taken from a literature textbook for Russian high-school seniors. Eight multiple-choice questions parallel and similar to the English questions were constructed to assess reading comprehension of the Russian passage.

For bilinguals, comprehension of content, $t(14) = 0.38, p = .71$, was comparable across Russian and English. However, bilinguals were significantly faster when reading in English ($M = 2.71$ words/s, $SE = 0.12$) than in Russian ($M = 2.12$ words/s, $SE = 0.11$), $t(14) = 4.44, p < .01$, and showed a trend for being more accurate when reading English ($M = 0.03$ errors/total words, $SE = 0.004$) than when reading Russian ($M = 0.04$ errors/total words, $SE = 0.008$), $t(14) = 1.89, p = .08$.

Design

Two dependent variables were considered: the proportion of eye movements to the distractor word and the reaction time to naming a picture. The experiment followed a one-way three-level repeated-measures design. Condition (a within-subjects variable) included three levels: one experimental level (Russian word) and two control levels (nonword control condition and English translation condition). As customary in PWI tasks, the same picture was presented for each of the three conditions per trial.

Materials

Target pictures and distractor words in each of the three conditions used in Experiment 1 are listed in Table 1. Twenty-two 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-two Russian words that were semantically related to picture names (i.e., belonged to the same superordinate category) were selected. Russian words were then translated into English to yield 22 English translation-equivalent stimuli. Frequencies of the English words were determined using the CELEX lexical database (Baayen, Piepenbrock, & Gulikers, 1995). Frequencies of the Russian words were determined using two sources: an older dictionary of frequencies of Russian (Zasorina, 1977) and a new online Russian frequency dictionary (Sharoff, 2002). Computations of frequencies in both sources are based on the number of occurrences of a word per 1 million written words. The difference between average frequencies of Russian words ($M = 143.92$, $SD = 372.18$) and their English translations ($M = 31.61$, $SD = 44.93$) was not statistically significant, paired samples $t(22) = 1.54$, $p = .14$. Although frequency differences for crosslinguistic stimuli are known to play a role in how bilinguals process words, in this experiment the frequencies for the corresponding stimuli could not be equated for the two languages, as there was only a limited number of Russian stimuli available based on the selection criteria.

Control nonword stimuli for the Russian words were constructed by creating nonwords comparable to the Russian words in length, syllable structure, and bigram frequencies (see Table 2). Bigram frequencies were calculated using the CLAN program of the CHILDES database (MacWhinney, 2000). Paired-samples t-tests confirmed that Russian stimuli ($M = 2576.9$, $SE = 1371.83$) and nonword control stimuli ($M = 2748.05$, $SE = 1367.00$) were similar in their bigram frequencies, $t(21) = 0.14$, $p = .89$. In order to eliminate a possible

Table 1 Word frequencies of orthographic Russian words and of English translations in Experiment 1

Picture name	Orthographic Russian word	Frequency (Sharoff)	English translation	Frequency (CELEX)
Chicken	YTKA	20.00	Duck	4
Collar	PYKAB	79.08	Sleeve	10
Crow	COBA	7.41	Owl	3
Door	OKNO	441.58	Window	139
Duck	KYPA	19.22	Chicken	6
Envelope	MAPKA	45.11	Stamp	11
Eyebrow	BEKO	24.67	Eyelid	2
Flower	TPABA	145.00	Grass	88
Fly	KOMAP	24.06	Mosquito	3
Leg	PYKA	1,787.85	Arm	110
Lobster	PAK	10.41	Crawfish	.0
Mosquito	OCA	6.55	Wasp	3
Mouth	HOC	252.49	Nose	76
Owl	BOPOHA	14.45	Crow	0
Palmtree	COCHA	38.07	Pinetree	12
Pig	KOPOBA	53.50	Cow	23
Plate	CTAKAH	111.10	Glass	132
Rake	COBOK	4.35	Shovel	3
Sink	KPAH	29.87	Faucet	2
Sleeve	BOPOT	133.88	Collar	19
Toilet	BAHHA	23.28	Bathtub	2
Tree	BETKA	6.32	Branch	56
Mean		143.92		31.61
SD		372.18		44.93

confound of font type, all stimuli (Russian words, nonword controls, and English words) were spelled using the Times New Roman font.

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 of 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. Quadrants were assigned arbitrary numbers of 1, 2, 3, and 4, with 1 identifying the top left quadrant, 2 identifying the top right quadrant, 3 identifying the

Table 2 Bigram frequencies of orthographic Russian words and of nonword controls in Experiment 1

Orthographic Russian word	Bigram frequency	Nonword control stimulus	Bigram frequency
YTKA	150.67	IQTA	179.67
PYKAB	837.25	JUQOV	785.50
COBA	4,587.67	FODA	2,681.67
OKNO	1,939.67	OSNO	2,286.33
KYPA	1,619.67	KILA	2,645.67
MAPKA	2,186.00	NALTA	2,660.25
BEKO	1,491.33	MEKO	2,252.00
TPABA	2,622.50	TKAMA	2,252.25
KOMAP	3,126.50	SUNAK	3,652.75
PYKA	186.00	JIKU	195.33
PAK	2,951.00	LUT	3,391.00
OCA	4,677.00	OTA	5,045.50
HOC	3,392.00	LOD	3,900.50
BOPOHA	3,092.00	FOLOMA	4,432.00
COCHA	5,759.00	TOSNA	3,271.25
KOPOBA	2,395.80	TOLOFA	4,183.40
CTAKAH	2,337.20	QTAKAJ	1,649.60
COBOK	3,840.75	TOSUK	2,771.75
KPAH	1,527.33	MTOJ	1,614.33
BOPOT	3,604.50	DOLUN	4,168.50
BAHHA	2,038.75	GAVVA	1,534.25
BETKA	2,439.50	GETKA	2,796.25
Mean	2,576.90		2,748.05
SD	1,371.83		1,367.00

bottom left quadrant, and 4 identifying the bottom right quadrant. In addition to target picture presentations, 16 filler picture stimuli were included.

The presentation sequence was as follows: An interstimulus interval (ISI) equal to 1000 ms was followed by presentation of a black cross in the middle of the screen for 500 ms, after which the target stimulus was presented. The stimulus onset asynchrony (SOA) between the picture and the word was equal to zero. There was no limit to how long the target stimulus stayed on the screen; however, as soon as the microphone was triggered by the response, the next ISI was presented.

Apparatus

All stimuli were presented on a G5 Macintosh Monitor using SuperLab experimental software (Cedrus Corporation, 2001). A Logitech microphone was connected to the computer, which recorded naming times. Naming times were measured from the presentation of the picture to the onset of triggering the microphone response by the participant's voice. The amplitude threshold for the microphone was set at 5 dB—a signal level that appeared to be optimal for all participants. A headband-mounted ISCAN eye tracker 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 FinalCut Editing software for frame-by-frame playback analysis.

Procedure

All participants were tested individually. Training for the PWI task was completed first. The training procedure was implemented for two reasons: to familiarize the participants with the picture names, thereby assuring consistency in naming across participants, and to accustom them to the level of loudness needed to activate the microphone. During training, the participant was seated about 17 in. (40 cm) from the computer screen, with the microphone positioned 5 in. (12.70 cm) from the participant's mouth. 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 signal from the microphone activated the experimental software, and the picture was replaced by its target name. The participant was instructed to compare the name he/she gave to the picture with its target name; after establishing that they were the same, or memorizing the target name if they were not, the participant could access the next picture by pressing the space bar on the keyboard. If the participant misnamed more than 5 pictures out of the total of 38, the training was repeated.

After training, the eye-tracking equipment was calibrated on nine fixation points. The fixation values were then mapped onto the corresponding monitor locations; the fixation location was indicated by a white crosshair 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; the participant was also instructed to name pictures into the microphone as fast and as accurately as possible and to ignore the text on the screen. Accuracy of naming was later coded using the digitally recorded data.

At the end of the experimental session, the reading ability measure and the LEAP questionnaire were administered to each participant.

Coding

The proportion of eye movements, reaction times, and accuracy of naming data were collected for each participant. The eye-tracking data, consisting of crosshairs superimposed onto the field-of-view, were recorded onto digital tapes, which were later loaded onto FinalCut Editing software. An eye movement to the word was considered to have occurred when the crosshairs moved into the quadrant containing the word. A completed movement into the quadrant was coded as 1, whereas no movement was coded as 0. For each condition, 1's and 0's were added together and then divided by the total number of trials in the condition, yielding the proportion of word fixations per condition for each participant. Ten percent of the eye-tracking data were coded by a second, independent coder who did not speak Russian. Point-to-point reliability for coding of eye movements was 96%. Reaction times were recorded using SuperLab software, which measured the time lapse between the presentation of the picture and the initiation of the vocal response into the microphone. Trials in which the microphone was activated by a sound other than picture naming (e.g., coughs) were omitted from analyses; trials in which the participant's response failed to activate the microphone were analyzed after the experiment was completed, and the reaction times to the stimuli were calculated manually based on recorded audio files available for each participant. Accuracy was assessed by reviewing the participant's recorded performance.

Data acquired from reading measures were analyzed for the following variables: (a) speed of reading (total number of words in the passage/total time taken to read the passage), (b) accuracy of reading (total number of errors made during reading of passage/total number of words in the passage), and (c) reading comprehension (number of multiple-choice questions answered correctly out of eight). All types of dysfluency during reading (e.g., phoneme, syllable, word, and phrase repetitions), word omissions, mispronunciations, and misreadings were coded as errors.

Results

Participants made errors on 4.40% of trials. Picture-naming errors (1.11%) were analyzed separately, and false-start errors (3.29%) were omitted from analyses.

Two items (*plate* and *mosquito*) were found to consistently yield unusually high reaction times and the greatest number of naming errors (e.g., "circle" and "oval" for *plate*; "fly" and "insect" for *mosquito*), most likely due to poor pictorial presentations. As a result, these items were omitted from analyses in Experiments 1 and 2. Outliers (items that resulted in reaction times that were three standard deviations greater than the mean reaction time for that participant) were replaced with the appropriate mean + 3 *SD* value (2.14% of the remaining trials).

By-Item Analyses

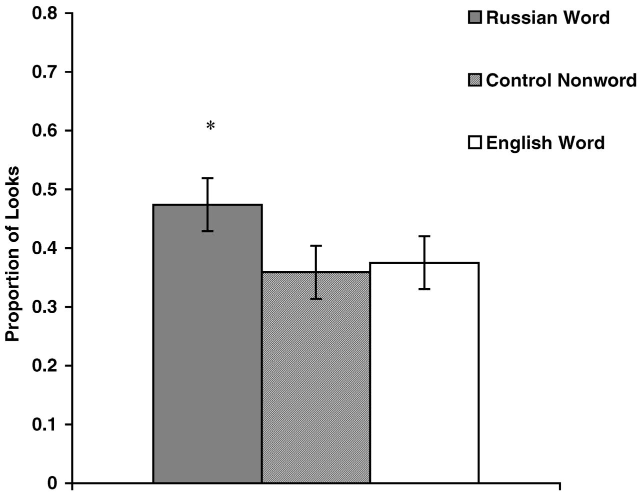
By-item analyses were conducted first, in order to establish the link between eye movements to distractor words and reaction times to pictures. Data for each item were averaged across participants, yielding two reaction time data points per item: where the distractor word drew participants' eye movements, and where it did not. Differences in reaction times for items that drew eye movements versus items that did not were analyzed using a 2×3 ANOVA, with looks (looks, no looks) and condition (Russian word, nonword control, English translation control) as between-subjects independent variables. Results revealed a main effect of looks, with items that drew eye movements yielding higher reaction times ($M = 920.86$, $SE = 13.96$) than items that did not draw eye movements ($M = 779.96$, $SE = 13.39$), $F(1, 217) = 53.07$, $p < .001$. No other main effects or interactions were observed, suggesting that looking at a distractor word resulted in longer picture-naming times, regardless of experimental condition. Therefore, subsequent analyses were conducted by subject only, with data averaged per subject for each of the three conditions.

Proportion of Eye Movements to the Distractor Word

A one-way three-level repeated-measures ANOVA, with condition (Russian word, nonword control, English translation control) as a within-subjects variable, was used to analyze the proportion of eye movements to the three types of distractor word. The ANOVA yielded a main effect of condition, $F(1, 14) = 4.39$, $p < .05$ (Figure 3). Bilinguals looked longer at the Russian words ($M = 0.47$, $SE = 0.06$) than at the nonword control stimuli ($M = 0.36$, $SE = 0.05$), $F(1, 14) = 7.76$, $p < .05$, partial $\eta^2 = 0.36$, and at the English translations ($M = 0.38$, $SE = 0.04$), $F(1, 14) = 4.94$, $p < .05$, partial $\eta^2 = 0.26$.

Reaction Times

A one-way three-level repeated-measures ANOVA with condition (Russian word, nonword control, English translation control) as a within-subjects variable, yielded a significant main effect of condition, $F(1, 14) = 15.57$, $p < .01$



*p<0.05

Figure 3 Experiment 1. Mean proportion of looks to distractor stimuli when distractors were Russian words, bigram-matched nonword control stimuli, and English translation equivalents.

(Figure 4). Bilinguals had longer reaction times for pictures accompanied by Russian words ($M = 872.31$, $SE = 22.63$) than for pictures accompanied by nonword controls ($M = 830.64$, $SE = 22.97$), $F(1, 14) = 4.59, p < .05$, partial $\eta^2 = 0.25$, or by English translation controls ($M = 827.85$, $SE = 19.71$), $F(1, 14) = 15.57, p < .01$, partial $\eta^2 = 0.53$.

Error Analysis

On the PWI task, bilingual participants made 11 misnaming errors across all trials. Of these, five misnaming errors were made when the distractors were English words and six were made when the distractors were Russian words, such as naming the picture of *chicken* “duck” when the word on the screen was YTKA, a Russian word for “duck.” These numbers were too low to warrant a formal statistical analysis, but they are considered in the *Discussion* section because of their value in understanding cognitive processes that took place during the PWI task in Russian-English bilinguals.

Control Comparisons for Experiment 1: Position of Distractor Word

In Experiment 1, the position of a word in relation to a picture was counterbalanced across trials, but it remained constant within a trial in order to make

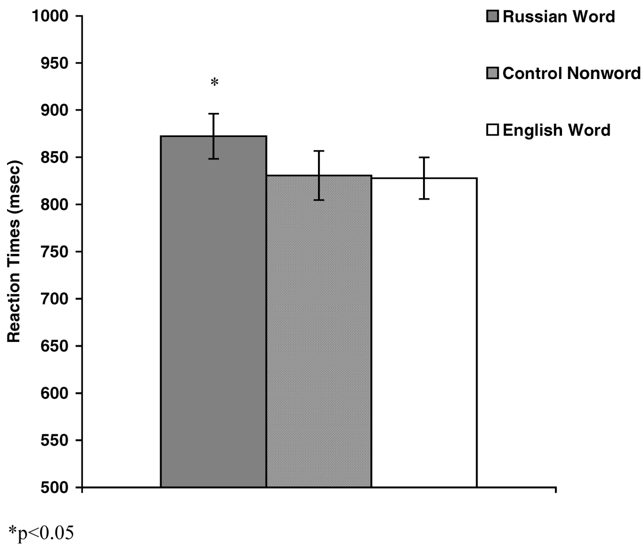


Figure 4 Experiment 1. Reaction times for naming pictures in English when distractors were Russian words, bigram-matched nonword control stimuli, and English translation equivalents.

comparisons across conditions possible. In order to determine if the position of the distractor word on the screen had an effect on the dependent variables of interest and/or interacted with experimental condition, a 4×3 within-subjects ANOVA, with quadrant (1, 2, 3, 4) and condition (Russian word, nonword control, English translation) as within-subjects variables, was used to examine the proportions of eye movements and reaction times.

Proportion of Eye Movements to the Word

The 4×3 ANOVA revealed a main effect of word position, $F(1, 96) = 66.73$, $p < .01$, suggesting that the position of words on the screen affected the proportion of eye movements to the word. Participants looked significantly more often at the words in the first quadrant than in the second, third, or fourth quadrants. They also looked more at words in the second quadrant than in the third or fourth quadrants (see Table 3). Interaction between word position and condition was not significant ($p = .9$), suggesting that word position affected eye-movement patterns comparably for the three conditions.

Reaction Times

A 4×3 ANOVA with reaction times as a dependent variable yielded a main effect of word position, $F(1, 96) = 7.56$, $p < .01$, suggesting that the position

Table 3 Control comparisons for Experiment 1: Effect of distractor word position on proportion of eye movements and on reaction times

Quadrant position of distractor word	Mean proportion of eye movements (*SE*)	Mean reaction times (ms) (*SE*)
Quadrant 1	0.68 (0.03)	864.07 (21.06)
Quadrant 2	0.48 (0.03)	894.71 (21.06)
Quadrant 3	0.17 (0.03)	818.64 (17.19)
Quadrant 4	0.21 (0.03)	775.13 (17.19)

of words on the screen affected picture-naming times. Participants had longer reaction times to stimuli when distractor words appeared in the first quadrant than when they appeared in the fourth quadrant. They also had longer reaction times to stimuli when the words were in the second quadrant than in the third or fourth quadrants (see Table 3). Interaction between word position and condition was not statistically significant ($p > .6$), suggesting that the position of the distractor word on the screen affected the participants similarly for all conditions.

As suspected, the position of a distractor word in relation to a picture influenced the proportion of looks and picture-naming times, with distractors in upper quadrants drawing more looks and resulting in longer picture-naming times than distractors in lower quadrants. The lack of significant interactions between word position and condition suggests that position effects did not influence the observed patterns of results for different conditions. This finding is not surprising given that for each picture-word combination, the position of both the picture and the distractor word remained constant for each condition within a trial.

Discussion

Results of Experiment 1 demonstrated that Russian-English bilinguals looked at nonwords that constituted Russian words more than at control nonwords or at English translation controls. This finding indicates that information in the nontarget language drew bilinguals' eye movements and suggests that the nontarget Russian input was detected and recognized during an English processing task despite conflicting letter-to-sound mappings for the two languages. These results reinforce the idea that both languages known to a bilingual are activated during visual word recognition (e.g., Bijeljac-Babic et al., 1997; De Groot et al., 2000) and extend it further to suggest that orthographic information common to two languages can activate the nontarget language, even when it maps onto distinct phonological representations for the two languages. Moreover, these findings demonstrate that eye movements effectively differentiated bilingual performance on the three conditions of interest and suggest that the addition of an eye-tracking component could provide a reliable means of measuring word recognition in a modified version of the PWI task.

The finding that eye-movement patterns were closely approximated by reaction-time patterns suggests that, in this experiment, recognition of nontarget-language information affected target-language production. Russian-English bilinguals were found to have longer reaction times when naming pictures accompanied by English nonwords that constituted Russian words than by English control nonwords that were also nonwords in Russian. Moreover, picture-naming times were delayed by Russian words compared to English translation controls. The prediction that Russian words and English translation controls would draw equal proportions of eye movements and would delay picture naming in English to a similar degree was not supported. Instead, Russian-English bilinguals in Experiment 1 were more distracted by nontarget Russian words than by their English translations. This pattern of results could be due to a number of factors. For instance, it is possible that participants' expectations for the task played a role in the observed pattern of results. Because training and testing were conducted in English, the unexpected presence of Russian words on the computer screen might have drawn more attention than the presence of English words.

It is also possible that relative language proficiency and language exposure variables have contributed to the findings. Although Russian-English bilinguals tested in this study were highly proficient speakers of both languages, they were all living in the United States and were attending an American university or working in an American environment during the time of the experiment. Therefore, their exposure to English was significantly higher than their exposure to Russian. Moreover, reading tests administered at the end of the experiment suggested that participants were more proficient at reading English than at reading Russian, especially in terms of reading speed. It is likely that the higher exposure to English and superior English-reading skills have enabled Russian-English bilinguals to process English words with greater efficiency. This processing efficiency might have allowed Russian-English bilinguals to detect English distractors without allocating eye movements to them, thus reducing the proportion of eye movements to English distractors compared to Russian distractors. Reduction in eye movements would then result in faster naming times for pictures accompanied by English words.

The finding of longer naming times for pictures accompanied by Russian words suggests that recognition of distractor nonwords as viable Russian words resulted in delayed picture-naming times for the Russian-English bilinguals; that is, recognition of nontarget-language information was followed through with processing of the distractor word to the output stage. This observation is further supported by examination of error data. Although bilingual participants made only six misnaming errors when the distractor was a Russian word, the mere fact that these errors existed supports the idea that orthographic information present in these stimuli activated the relevant lexico-semantic information for Russian. Whereas the occurrence of errors such as these suggests that Russian written stimuli interfered with English picture naming, the finding that none of the bilingual participants had switched into Russian when naming pictures suggests that this interference was not direct. Instead, a spontaneous translation of the Russian distractor into English had occurred, and this, in turn, interfered with picture naming. This pattern of errors appears to be consistent with the *indirect* interference hypothesis offered by Costa et al. (1999), who suggested that the nontarget-language item does not interfere with the selection of the picture name directly. Instead, activation of the nontarget lexical item leads to activation of its corresponding translation equivalent, which then competes for selection of the picture name within the target-language lexicon.

In addition to indirect interference, interference of the nontarget-language item with target-language picture naming could be due to at least two other factors. The difference in reaction times to pictures accompanied by Russian words versus nonwords may (a) be due to *direct* interference of the nontarget-language lexical item with target-language lexical selection or (b) be an artifact of the stimuli (Russian words used in this experiment were frequent and highly recognizable Russian words). The presence of frequent and highly familiar Russian words might have activated the Russian lexicon so strongly that it delayed naming in the target language. The direct versus indirect interference hypotheses as possible explanations for results of Experiment 1 will be considered further in the General Discussion section. The explanation of results in terms of stimulus artifacts will be discussed here, as it has bearings on Experiment 2.

Explaining differences in reaction-time patterns between Russian words and nonword controls in Experiment 1 as being due to salience of Russian words does not negate the finding that Russian words were recognized despite involvement in the English task, thus suggesting parallel language processing in bilinguals. However, it does raise the possibility that strong interference effects (like the ones observed in Experiment 1) might only be obtained when the distractor word is a highly salient word from the nontarget language and suggests that a more subtle manipulation of the stimuli might not result in the same pattern of results. Experiment 2 was conducted in order to test the hypothesis that a less salient presentation of a Russian distractor word would result in a pattern of results similar to that obtained in Experiment 1. For this purpose, Russian stimuli used in Experiment 1 were spelled using English letters. This was possible because of the different orthography-to-phonology mappings between the two languages. For instance, the Russian word for *owl* is COBA, which is pronounced as /sava/ in Russian, but as /koba/ if using English letter-to-phoneme mappings. It is possible, then, to maintain the phonological form of the Russian word, but spell it using English letters (i.e., SAVA). When pronounced according to English letter-to-sound conversion rules, the letter string SAVA maps onto a phonological representation of a Russian word. However, in its alphabetic written form, the word contains minimal information for the Russian language and in fact contains English-specific letters.

Experiment 2 not only tested the hypothesis that salience of the Russian stimuli in Experiment 1 drove the observed effects but also examined whether nontarget-language phonology can be recognized during a target-language task, despite the absence of nontarget-language orthography. Russian stimuli in Experiment 2 mapped onto meaningful Russian words via the phonological form only, as their orthographic form carried little information for Russian. The role of phonology in processing written language has been supported by a number of studies (e.g., Ferrand & Grainger, 1994; Jescheniak & Schriefers, 2001; Nas, 1983) and has been incorporated into nearly all computational models of reading (e.g., Coltheart et al., 1993, 2001; Dijkstra & Van Heuven, 1998; 2002; Seidenberg, & McLelland, 1989). Studies with bilinguals suggest that phonological information for a nontarget language is activated when reading in a target language (e.g., Brysbaert et al., 1999; Dijkstra et al., 1999), even when the two languages do not share orthography (e.g., Tzelgov et al., 1996). Therefore, it was hypothesized that Russian words used in Experiment 2 would be recognized by Russian-English bilinguals, who would then experience interference with picture naming in English. These results would suggest that nontarget-language phonology can be activated during target-language processing, despite discrepancies between the orthographies of the two languages. Moreover, if the results of Experiment 1 were driven by salience of Russian distractor words, then the pattern of results in Experiment 2 should be different from that in Experiment 1; namely recognition and interference effects obtained in Experiment 2 should be weaker than recognition and interference effects obtained in Experiment 1. If, however, the results of Experiment 1 were not contingent upon saliency of Russian stimuli, then the two experiments should converge in demonstrating that any information for the nontarget language, salient or not, is recognized and can interfere with picture naming in the target language.

Experiment 2: Recognition and Interference of Nontarget-Language Phonology

Experiment 2 examines how Russian-English bilinguals process letter strings that contain letters specific to the English alphabet but that map onto viable phonological Russian words. The proportions of eye movements made by Russian-English bilinguals to nonword English stimuli that constituted phonological words in Russian (e.g., SAVA) were compared to proportions of eye movements to bigram-matched nonword controls (e.g., RODA) and to English translation controls (OWL). Four predictions were made:

1. It was predicted that phonological Russian input would be recognized and draw greater proportion of eye movements than nonword controls.
2. It was predicted that the recognized phonological Russian words would be processed to the level of phonological lexicon and would interfere with picture naming in the target language to a greater extent than nonword controls.
3. It was predicted that both phonological Russian words and their English translation equivalents would be recognized during the English naming task and thus draw similar proportions of eye movements.
4. It was predicted that Russian words and English translation equivalents would interfere with picture naming in English to the same extent.

Method

Experiment 2 followed a one-way three-level repeated-measures design, with condition (phonological Russian stimuli, nonword controls, English translation controls) as the within-subjects variable. Russian-English bilinguals who participated in Experiment 1 also completed Experiment 2.

Materials

Twenty-two target pictures of common concrete objects (both animate and inanimate) used in Experiment 1 were used in Experiment 2. Twenty-two words that were semantically related to picture names (i.e., belonged to the same superordinate category) were selected (see Table 4). In Experiment 2, these words were phonological Russian stimuli—stimuli that were phonological representations of Russian words, spelled using letters of the English alphabet.

Table 4 Word frequencies of phonological Russian words and of English translations in Experiment 1

Picture name	Phonological Russian word	Frequency (Sharoff)	English translation	Frequency (CELEX)
Chicken	UTKA	20.00	Duck	4
Collar	RUKAV	79.08	Sleeve	10
Crow	SAVA	7.41	Owl	3
Door	AKNO	441.58	Window	139
Duck	KURA	19.22	Chicken	6
Envelope	MARKA	45.11	Stamp	11
Eyebrow	VEKA	24.67	Eyelid	2
Flower	TRAVA	145.00	Grass	88
Fly	KAMAR	24.06	Mosquito	3
Leg	RUKA	1,787.85	Arm	110
Lobster	RAK	10.41	Crawfish	.0
Mosquito	ASA	6.55	Wasp	3
Mouth	NOS	252.49	Nose	76
Owl	VARONA	14.45	Crow	0
Palm tree	SASNA	38.07	Pinetree	12
Pig	KAROVA	53.50	Cow	23
Plate	STAKAN	111.10	Glass	132
Rake	SAVOK	4.35	Shovel	3
Sink	KRAN	29.87	Faucet	2
Sleeve	VORAT	133.88	Collar	19
Toilet	VANNA	23.28	Bathtub	2
Tree	VETKA	26.32	Branch	56
Mean		143.92		31.61
SD		372.18		44.93

Control stimuli for the phonological Russian words were constructed to be comparable to Russian words in length and bigram frequencies (see Table 5). Where the bigram frequencies of Russian phonological stimuli were comparable to those of the corresponding Russian stimuli in Experiment 1, the control nonword stimuli from Experiment 1 were used. Where the two types of Russian stimulus differed greatly in their English bigram frequencies, new bigram-matched control stimuli were constructed. A paired-samples t-test confirmed that phonological Russian stimuli ($M = 4171.64$, $SD = 2140.25$) did not differ from nonword control stimuli ($M = 4130.80$, $SD = 1963.73$) in their bigram frequencies, $t(21) = -0.77$, $p = .45$. Stimuli for Experiment 2 were presented

Table 5 Bigram frequencies of phonological Russian words and of nonword controls in Experiment 2

Phonological Russian word	Bigram frequency	Nonword control	Bigram frequency
UTKA	1,544.00	ITKA	2,050.33
RUKAV	1,306.00	JUQOV	1,241.50
SAVA	1,997.00	FODA	2,147.67
AKNO	1,533.33	EKMI	1,623.67
KURA	5,544.67	TILA	6,023.33
MARKA	4,366.25	NALTA	5,213.00
VEKA	2,711.67	MEKU	2,209.00
TRAVA	5,090.25	KRAMA	4,920.00
KAMAR	5,039.50	TONAK	5,504.00
RUKA	1,167.67	MIKU	1,652.33
RAK	6,236.00	GAN	6,993.00
ASA	4,243.50	OTA	5,045.50
NOS	2,919.50	LOD	3,900.50
VARONA	6,814.60	FOLOMA	4,432.00
SASNA	2,747.25	LOSLA	4,870.00
KAROVA	4,277.40	TOLOFU	4,095.40
STAKAN	6,545.40	STARAM	8,995.00
SAVOK	1,904.00	VOSUK	1,832.75
KRAN	7,369.67	TROM	6,223.00
VORAT	8,283.00	DOLUN	4,136.75
VANNA	4,472.25	FAMMA	3,000.50
VETKA	3,321.50	GETMA	4,046.75
Mean	4,171.64		4,130.80
SD	2,140.25		1,963.73

in a mixed order with stimuli for Experiment 1, in order to minimize order effects in the data.

Apparatus, Procedure, and Coding

The apparatus and methodology used in Experiment 1 were also used in Experiment 2. The testing and coding followed in Experiment 2 were the same as in Experiment 1. Ten percent of the eye-tracking data obtained in Experiment 2 were coded by an independent rater; point-to-point reliability for coding of eye movements was 96%.

Results

Trials on which participants made errors accounted for 2.45% of the data. Although naming errors (0.96%) were analyzed separately, trials where errors were due to equipment malfunction or to triggering of the microphone by an extraneous sound (1.49%) were omitted from the analyses. Outliers (items that resulted in reaction times that were three standard deviations greater than the mean reaction time for that participant) were replaced with the appropriate mean + 3 *SD* value (2.12% of the remaining trials).

By-Item Analysis

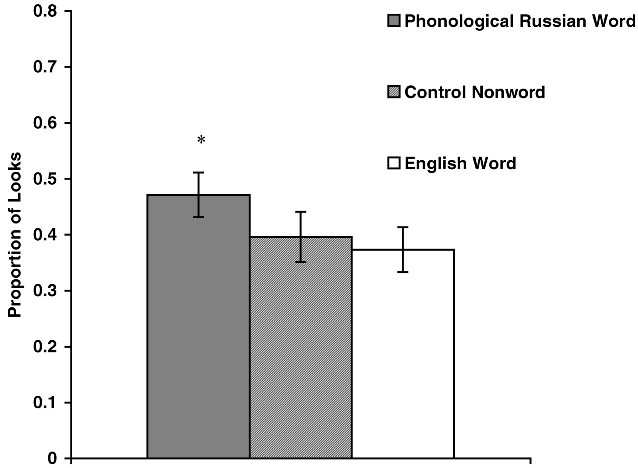
Similar to Experiment 1, reaction-time data for each item were averaged across participants, yielding two data points per item: where the item drew participants' eye movements and where it did not. Differences in reaction times for items that drew eye movements versus items that did not were analyzed using a 2×3 ANOVA, with looks (looks, no looks) and condition (phonological Russian word, nonword control, English translation control) as between-subjects independent variables. Results revealed a main effect of looks, with items that drew eye movements yielding longer reaction times ($M = 921.87$, $SE = 15.30$) than items that did not draw eye movements ($M = 787.77$, $SE = 14.41$), $F(1, 215) = 40.72$, $p < .0001$. No other main effects or interactions were observed, suggesting that looking at a distractor word resulted in longer picture naming times, regardless of experimental condition.

Proportion of Eye Movements

The eye-movement data were analyzed using a one-way three-level repeated-measures ANOVA, with condition (phonological Russian words vs. nonword controls vs. English translation controls) as the within-subjects variable. Results (depicted in Figure 5) revealed a main effect of condition, $F(1, 14) = 6.54$, $p < .05$. Bilinguals looked more at the phonological Russian words ($M = 0.47$, $SE = 0.05$) than at the nonword controls ($M = 0.40$, $SE = 0.04$), $F(1, 14) = 6.02$, $p < .05$, partial $\eta^2 = 0.30$, or at the English translation controls ($M = 0.37$, $SE = 0.04$), $F(1, 14) = 6.54$, $p < .05$, partial $\eta^2 = 0.29$.

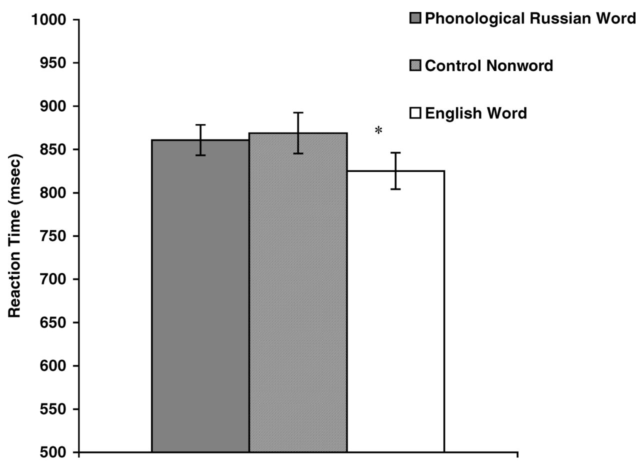
Reaction Times

A one-way three-level repeated-measures ANOVA, with condition (phonological Russian words vs. nonword controls vs. English translation controls) as a within-subjects variable revealed a significant main effect of condition, $F(1, 28) = 9.82$, $p < .01$ (as depicted in Figure 6). Bilinguals had longer reaction times to pictures accompanied by phonological Russian words



*p<0.05

Figure 5 Experiment 2. Mean proportion of looks to distractor stimuli when distractors were phonological Russian words, bigram-matched nonword control stimuli, and English translation equivalents.



*p<0.05

Figure 6 Experiment 2. Reaction times for naming pictures in English when distractors were phonological Russian words, bigram-matched nonword control stimuli, and English translation equivalents.

($M = 860.83$, $SE = 15.03$) than to pictures accompanied by English translation controls ($M = 825.17$, $SE = 19.76$), $F(1, 14) = 5.63$, $p < .05$, partial $\eta^2 = 0.29$. In addition, bilinguals had longer reaction times to pictures accompanied by nonword control stimuli ($M = 868.86$, $SE = 19.79$) than to pictures accompanied by English translation controls ($p < .05$). Reaction times to pictures accompanied by phonological Russian words and nonword controls were similar ($p > .6$, partial $\eta^2 = 0.02$).

Error Analysis

Bilingual participants made three misnaming errors in the picture—phonological Russian word condition (e.g., naming a picture of a *collar* "sleeve" when the distractor word was RUKAV ("sleeve" in Russian, the actual spelling of which would be PYKAB).

Control Comparisons for Experiment 2: Position of Distractor Word

In Experiment 2, the position of the picture and the distractor word for each trial remained constant in order to make comparisons across the three conditions possible. A 4 × 3 repeated-measures ANOVA, with quadrant (1, 2, 3, 4) and condition (phonological Russian word, nonword control, English translation control) as within-subjects variables, was used to analyze the effect of quadrant position on each dependent variable.

Proportion of Eye Movements to the Word

The position of words on the screen was found to affect the proportion of eye movements to the word, $F(1, 95) = 56.35$, $p < .01$. Participants looked significantly more at the words in the first quadrant than in the second, third, or fourth quadrants. They also looked more at the words in the second quadrant than in the third or fourth quadrants (see Table 6). Condition did not interact significantly with word position ($p > .7$), suggesting that position of words on the screen affected the participants similarly across all three conditions.

Reaction Times

The position of words on the screen was found to affect reaction times, $F(1, 95) = 3.36$, $p < .05$. All participants had longer reaction times to stimuli when words were in the first, second, and third quadrants than when they were in the fourth quadrant (see Table 6). Condition did not interact significantly with word position ($p > .2$), suggesting that the position of words on the screen affected reaction times in all conditions in a similar manner.

Table 6 Control comparisons for Experiment 2: Effect of distractor word position on proportion of eye movements and on reaction times

Quadrant position of distractor word	Mean proportion of eye movements (*SE*)	Mean reaction times (ms) (*SE*)
Quadrant 1	0.66 (0.03)	864.63 (25.05)
Quadrant 2	0.50 (0.03)	862.24 (25.05)
Quadrant 3	0.19 (0.03)	856.05 (20.79)
Quadrant 4	0.21 (0.03)	782.82 (20.45)

Similar to position effects in Experiment 1, position effects in Experiment 2 suggested that distractor words in the top quadrants drew more looks and resulted in longer naming times than distractor words in the bottom quadrants. The lack of significant interaction between condition and word position variables suggested that the positional effects observed did not influence the patterns of results obtained for different conditions.

Discussion

The results of Experiment 2 demonstrated that Russian-English bilinguals looked at phonological Russian words more reliably than at bigram-matched nonword controls. This finding suggests that Russian-English bilinguals were sensitive to Russian phonological information contained in the distractor words. This pattern of results is similar to the pattern of results in Experiment 1 and suggests that information for the nontarget language does not have to be highly salient in order to be recognized; that is, even when distractor words contained English-specific letters, the presence of Russian phonological information effectively drew bilinguals' eye movements. In fact, direct comparisons of effect sizes for pairwise comparisons between the proportion of looks to orthographic Russian words and nonword controls in Experiment 1 (partial $\eta^2 = 0.36$) and the proportion of looks to phonological Russian words versus nonword controls in Experiment 2 (partial $\eta^2 = 0.30$) revealed comparable effect sizes, suggesting that the strength of activation of Russian words was comparable across the two experiments. However, Russian-English bilinguals made only three misnaming errors in Experiment 2, where the distractor word was a Russian word, compared to six misnaming errors in Experiment 1. This might suggest that the lower saliency of Russian words (and/or presence of English-specific orthography) in Experiment 2 made misnaming of pictures less likely.

Similar to results in Experiment 1, eye movements and picture-naming latencies differentiated phonological Russian words and English translation controls.

Russian-English bilinguals looked more and had longer naming times for Russian distractors than for English distractors. It is possible that, as in Experiment 1, this pattern was due to participants' expectations regarding the task, with nontarget-language stimuli drawing more looks and interfering with picture naming to a greater extent. However, whereas Experiment 1 included highly recognizable Russian words, Experiment 2 included less salient and less recognizable Russian words. Therefore, if expectations alone were driving the difference between Russian words and English translation controls, this difference would have been greater for Experiment 1 than for Experiment 2. Comparisons of eye-movement and reaction-time data for the two conditions suggest that that was not the case and that the differences between Russian words and English translation equivalents were comparable across the two experiments. It is more likely that faster reading speed in English and/or higher levels of English exposure have enabled the participants to process English distractors in a more efficient manner, thus reducing interference effects. Although proficiency and exposure variables might have contributed to the different patterns of results for Russian words and English translation equivalents, further research is necessary to examine the influence of each of these factors on bilinguals' ability to process target- and nontarget-language input.

Unlike the results of Experiment 1, the reaction-time data in Experiment 2 diverged from the eye-tracking data. In Experiment 2, Russian-English bilinguals experienced similar degrees of interference from phonological Russian words and nonword controls during picture naming in English. This pattern of results might have been driven by a number of factors. For one, it is possible that phonological Russian words and nonword controls in Experiment 2 interfered with picture naming in English to a similar degree, but for different reasons. For instance, phonological Russian words might have interfered with picture naming in English because they activated relevant lexical information for Russian, which, in turn, interfered with the selection of the English picture name. The nonword controls, on the other hand, might have interfered with picture naming because they were highly pronounceable[3] and, therefore, were processed to the level of phonological output, where they delayed the selection of appropriate phonological information for the picture name. An alternative explanation would suggest that phonological Russian words and nonword controls interfered with picture naming in English for the same reason. For instance, it is possible that both phonological Russian words and nonword controls were processed along the same nonword route. Both types of stimulus might have been treated as pronounceable nonwords by the Russian-English bilinguals and, therefore, interfered with picture naming to a similar degree.

The second explanation is compatible with that of Costa et al. (1999), who suggested that in a PWI task, processing of phonological information for a distractor word proceeds through a sublexical route, where letters are converted into their corresponding phonemes in a one-by-one fashion. The sublexical route, according to dual-route models of reading (e.g., Coltheart et al., 2001; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Ziegler et al., 2000), is specialized for processing nonwords and unfamiliar real words. Given that the phonological Russian words presented in Experiment 2 were, in effect, "unfamiliar real words," similar reaction-time patterns for phonological Russian words and nonword controls might be explained in terms of sublexical processing demands. This explanation would suggest that both phonological Russian words and nonword controls were processed along the sublexical route, thus yielding similar reaction times. However, the eye-tracking data obtained in Experiment 2 indicate that phonological Russian words were differentiated from nonword controls by Russian-English bilinguals at the recognition stage, with bilinguals looking at Russian words reliably more often than at nonword controls. Therefore, it seems unlikely that although phonological Russian words were *recognized* as such by Russian-English bilinguals, they were then processed as nonwords further along in the cognitive stream, during production. Instead, in light of the eye-tracking data, the first explanation seems more plausible; namely it is likely that phonological Russian words interfered with picture naming because phonological lexical information for Russian provided a viable alternative to the English picture name and, therefore, competed with it for selection. Control nonwords, on the other hand, interfered with picture naming because they were highly pronounceable and activated their corresponding nonlexical phonology, which, in turn, interfered with selection of phonological form for the picture names. High pronounceability of the control stimuli would explain why bilingual participants did not demonstrate a difference in reaction times to phonological Russian words versus nonword controls.

General Discussion

Performance of Russian-English bilinguals on a PWI task modified for use with eye tracking was investigated in two experiments. Russian-English bilinguals were found to look more at Russian words than at nonword controls and English translation equivalents and were found to have longer naming times for pictures accompanied by Russian words than for pictures accompanied by nonword controls or by English translation equivalents (Experiment 1). Russian-English bilinguals were also found to look more at phonologically represented Russian words than at nonword controls or at English translation controls; however, naming times for pictures accompanied by phonological Russian words and nonword controls were similarly delayed compared to naming times for pictures accompanied by English translation controls (Experiment 2).

Use of eye-tracking technology in conjunction with the PWI task made it possible to examine both recognition of the nontarget language (as indexed by differences in eye-movement patterns to Russian words vs. nonword controls) and its subsequent interference with the selection of target-language items during production (as indexed by differences in reaction-time patterns to pictures accompanied by Russian words vs. nonword controls). As in traditional PWI experiments, in this research reaction-time data incorporated both the word recognition component and the picture-naming component. Findings of longer reaction times on those trials in which participants looked at distractor words versus those in which participants did not look at distractor words demonstrate that eye movements and reaction times function in conjunction with each other, with attention to the distractor word consistently delaying picture naming. However, not all distractors delayed picture naming to the same degree. Orthographically legal Russian words were recognized and interfered with picture naming in the target language to a greater extent than nonwords that did not contain orthographic information for Russian (Experiment 1). Conversely, phonological Russian words were recognized, but interfered with production in the target language to the same degree as the nonwords that did not contain phonological information for Russian (Experiment 2).

Reliable differences between bilinguals' eye-movement patterns for Russian words and nonword controls across the two experiments suggest that eye movements to distractor words in the PWI task might provide a stable measure of visual word recognition: Eye movements effectively differentiated performance on Russian words from performance on nonwords for Russian-English bilinguals. The finding that Russian-English bilinguals consistently showed more eye movements and longer reaction times in the Russian-word condition but not in the English-word condition was surprising. Bilinguals were expected to perform similarly in the Russian-word and the English-word conditions, compared to control nonwords. One possible explanation for this finding stems from the higher initial and overall activation of English compared to Russian in this experiment. Consequently, the presence of Russian distractor words on the computer screen might have been highly unexpected, in that training for the task took place in English, participants were told to name pictures in English, and Russian was not used during the experiment. As a result, Russian-English bilinguals might have been able to ignore English semantic distractors in the two experiments to a greater extent than Russian semantic distractors because English words fit better with their expectations for these experiments. Similar eye-movement patterns observed for nonword controls and English translation controls support this idea. Additionally, it is possible that Russian-English bilinguals were more proficient readers in English than in Russian. (Oral reading proficiency measures collected at the end of the two experiments demonstrated that bilingual participants read faster and more accurately in English than in Russian.) Higher reading proficiency in English might have allowed Russian-English bilinguals to glean the English words' meanings without overtly looking at them, thus reducing the number of looks to the English distractors. It is also possible that because English words were processed with greater speed than Russian words, they did not interfere with picture naming in English. More experiments are required in order to examine bilingual performance with English distractor stimuli in the PWI task accompanied by eye tracking. It is likely that if Russian-English bilinguals with a different proficiency profile were tested on the same paradigm, the opposite patterns for Russian words versus English translation equivalents would be obtained. If it is the case that higher English proficiency enabled Russian-English bilinguals to ignore English input, then testing Russian-English bilinguals with a lower English proficiency would reveal more eye movements and longer reaction times for English words than for Russian words. Alternatively, if the unexpectedness of Russian input influenced performance patterns in this experiment, then switching English and Russian as target and nontarget language, respectively, would serve to reverse the finding, and bilinguals' naming performance would be more disrupted by the presence of English distractors than by the presence of Russian distractors. Moreover, a reversal of Russian and English as target and nontarget languages would test the bidirectionality of crosslinguistic interference and would serve as a measure of dominance effects in bilingual language processing.

Eye-tracking data obtained from Experiments 1 and 2 demonstrate that recognition of nontarget-language information can take place within the context of a target-language task, despite conflicting letter-to-phoneme mappings for the two languages (as in Experiment 1) or the presence of letters specific to the target language (as in Experiment 2). This finding adds to the sizable body of literature that suggests parallel language processing for bilinguals' two languages in recognition tasks (e.g., Dijkstra & Van Heuven, 1998; 2002; Nas, 1983). Reaction-time data demonstrate that orthographic information for the nontarget language (i.e., low-bigram-frequency nonwords in the target language, but high-frequency words in the nontarget language) interferes with production *more* than other nonwords in the target language. Conversely, recognition of phonological information for the nontarget language (i.e., high-bigram-frequency nonwords in the target language and phonologically viable words in the nontarget language) interferes with production in the target language *as much as* other nonwords in the target language.

Eye-movement patterns across the two experiments indicate that nontarget-language information is invariably recognized as such, despite involvement in a target-language task. This is why both the orthographic Russian words and the phonological Russian words were differentiated by eye-movement patterns from nonword controls and English translation controls across both experiments. Reaction-time data, on the other hand, appear to indicate that pronounceability of distractor words, not their lexical status in either the target or the nontarget language, affects language production. Interference experienced by Russian-English bilinguals from phonological Russian words (Experiment 2) did not differ from the interference that they experienced from nonword controls. Therefore, interference caused by phonological Russian words might have been due to within-language interference effects, *not* to recognition of the nontarget-language information. It is possible that pronounceable sequences of letters delayed the selection of lexical phonology for the picture name and that this delay had little to do with parallel processing of nontarget-language information during target-language production. What is notable, however, is that the divergence of eye-tracking and reaction-time data demonstrates that the same information, although recognized as being relevant to the nontarget language, does not necessarily impact production in the target language to a greater degree than any other pronounceable letter string. Following this logic, reaction-time data in Experiment 1, with bilinguals demonstrating longer reaction times for pictures accompanied by orthographic Russian words than for pictures accompanied by nonwords of comparable bigram frequency, can be interpreted to suggest that a letter string, if pronounceable in *any* of the bilingual's languages, will be processed to the level of phonological output and interfere with naming.

As discussed within the context of Experiment 1, interference of nontarget-language items with target-language picture naming could be due to a number of factors. Both explanations offered in the discussion of results for Experiment 1 propose activation of the nontarget language during target-language production, but differ in the degree of parallel processing theorized for the nontarget language. One explanation would suggest that differences in reaction times to pictures accompanied by Russian words versus nonword controls might be due to *direct interference* from nontarget-language lexical items. This explanation has been previously offered when discussing similar degrees of interference experienced by bilingual participants during a PWI task from between-language and within-language semantic distractors (e.g., Hermans et al., 1999). Such an explanation postulates parallel activation of nontarget lexical phonology during a target-language task. Alternatively, findings of between-language semantic interference have been explained by *indirect interference*, where activation of a nontarget lexical item leads to activation of its corresponding translation equivalent. It is this translation equivalent that then competes for selection within the target-language lexicon, as suggested by Costa et al. (1999). The indirect interference hypothesis localizes comparable interference effects for between-language and within-language semantic distractors to the target-language phonological lexicon; that is, the nontarget language is activated in parallel only as far as the level of the nontarget-language lexicon, and the phonological specification of the distractor word occurs for the target language only. Theoretically, the first explanation would predict similarities in eye-movement and reaction-time patterns on a PWI task, with activation of nontarget-language words resulting in interference with target-language picture naming. The second explanation, on the other hand, might suggest a divergence of eye-movement and reaction-time data on a PWI task, with activation of nontarget-language words not necessarily resulting in direct interference with target-language picture naming.

The results of the current experiments cannot conclusively dissociate the two explanations offered above, because the *indirect interference* hypothesis, as offered by Costa et al. (1999) is rooted in bilingual performance on a PWI task with identity distractors (written picture names acting as distractors). Costa et al.'s experiments demonstrated that Spanish-Catalan bilinguals who were asked to name pictures in Spanish while being distracted by written names of pictures in Catalan (e.g., naming a picture of a table "*mesa*" in Spanish while the distractor word was TAULA "*table*" in Catalan) experienced facilitation, not interference of picture naming. If nontarget lexical phonology is activated in parallel to the target-language picture name, then identity distractors should interfere with picture naming, not facilitate it. Therefore, Costa et al. suggested that lexical phonology of the nontarget language is not activated and that interference obtained when the semantic distractor is presented in the nontarget language occurs via activation of its within-language translation equivalent. Because the present research did not have an identity distractor condition, it cannot dissociate between the two theories (direct vs. indirect interference); however, it offers a promising new tool for doing so. Thus, if the indirect interference hypothesis is correct, bilingual participants completing the PWI task modified for use with eye tracking and presented with distractor words that are identity distractors in the nontarget language should demonstrate eye movements to the nontarget-language identity distractors (because they are activated in parallel to the target language), but they should not show a delay in target-language picture naming.[4] Alternatively, if the direct interference hypothesis is correct, then eye movements and reaction times should show similar patterns for the nontarget-language identity distractors.

Future studies will examine the effects of semantic relatedness in the PWI task modified for eye tracking, by comparing eye-movement and reaction-time patterns to nontarget-language semantic distractors versus semantically unrelated distractors. If eye movements to a distractor word on a PWI task provide a measure of language recognition, then eye movements to the two types of stimulus should not be contingent upon semantic relatedness, and bilinguals should look at comparable-frequency distractor words from the nontarget language to the same extent, whether they are semantically related to picture names or not. Alternatively, it is possible that the cumulative effect of nontarget-language recognition and of semantic relatedness would increase the likelihood of looks to semantically related distractor words compared to semantically unrelated distractor words.

In conclusion, the present research combined eye-tracking technology with the PWI paradigm to examine recognition and interference of the nontarget language during target-language production in bilingual speakers. Eye movements to distractor words spatially separated from pictures effectively differentiated bilinguals' performance on nonwords that constituted Russian words from performance on stimuli that constituted nonwords in both languages. Eye-tracking patterns from the two experiments reiterate that for bilinguals, written input carrying lexical information for the nontarget language—orthographic *or* phonological—activates the nontarget language during a target-language task. Reaction-time data, on the other hand, suggest that production in the target-language is affected by lexical and nonlexical information from both languages. Divergence between eye-tracking and reaction-time data within the same bilingual participants suggests cognitive differences between recognition and production processes, with recognition being susceptible to all information pertinent to the nontarget language and production being susceptible to all pronounceable information, independent of the target language.

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Notes

1 Both Experiment 1 and Experiment 2 were piloted with monolingual speakers of English within the context of the first author's qualifying research project for

admission to PhD candidacy. Results revealed that spatially separating the distractor word and picture stimulus eliminated the Picture-Word Interference effects, with monolingual participants demonstrating comparable reaction times to Russian words, nonword controls, and English translation controls (all $p > .5$). These monolingual pilot data confirm that differences in reaction times obtained with bilingual participants are due to recognition of nontarget-language information contained within distractor words.

2 Rayner and Posnansky (1978) compared picture-naming latencies when pictures were accompanied by nonword homophones (e.g., BYRD for a picture of BIRD) versus nonword nonhomophones, such as BAID, and showed facilitation of picture naming when the picture was accompanied by BYRD versus BAID.

3 Phonological Russian words, spelled using English letters, were higher in English bigram frequencies than Russian words in Experiment 1. The nonword control stimuli were constructed to match Russian stimuli in bigram frequencies within each experiment. Therefore, control stimuli in Experiment 2 were higher in bigram frequencies than control stimuli in Experiment 1. As a result, the percentage of looks and reaction times for Russian words *relative* to nonword controls can be compared between the experiments. Future studies should further consider the role of pronounceability in bilingual language recognition and interference.

4 The authors thank Judith Kroll for this suggestion.

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