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Competing activation in bilingual language processing: Within- and between-language competition*

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Two eye-tracking experiments examined spoken language processing in Russian-English bilinguals. The proportion of looks to objects whose names were phonologically similar to the name of a target object in either the same language (within-language competition), the other language (between-language competition), or both languages at the same time (simultaneous competition) was compared to the proportion of looks in a control condition in which no objects overlapped phonologically with the target. Results support previous findings of parallel activation of lexical items within and between languages, but suggest that the magnitude of the between-language competition effect may vary across first and second languages and may be mediated by a number of factors such as stimuli, language background, and language mode.

Bilingualism presents a useful setting for exploring fundamental questions about the cognitive architecture of language and cognition. One of the most important questions in the bilingualism literature revolves around the nature of bilingual language processing. Is bilingual lexical processing language-specific, or is there overlap and interaction between lexical processing in the two languages? Early research suggests selective processing of the two languages in bilinguals, an idea that is not only plausible, but also intuitively attractive and cognitively efficient. Such a mechanism would protect a bilingual from spurious mappings onto the inappropriate lexicon. After all, it seems inefficient to activate words from a second language when the circumstances do not require it. Evidence in support of selective processing of independent lexicons comes from repetition priming in tasks such as lexical decision or word-fragment completion. Although significantly less time is required to make a lexical decision task following a same-language repetition, most studies fail to find any repetition advantage when the stimuli are repeated in different languages (Kirsner, Brown, Abrol, Chadha and Sharma, 1980; Gerard and Scarborough, 1989). Word-fragment completion studies led to similar results – performance was better only when the languages at study and test were the same (Watkins and Peynircioglu, 1983; Durgunoglu and Roediger, 1987), but no facilitation was found across languages. These and other studies (e.g., Ransdell and Fischler, 1987; Scarborough, Gerard and Cortese, 1984) have been interpreted to suggest that bilinguals can access each language independently without interference from the other language and that only one lexicon can be used at any given time. However, more recent evidence seriously challenges this account.

The first set of data supporting parallel activation of both languages in bilinguals comes from performance on a bilingual version of the Stroop task. The basic Stroop task consists of naming the ink colors of words that spell color names. Monolingual speakers usually show interference when the ink color and the word color are incongruent. This basic task was adapted for use with bilinguals by Preston and Lambert (1969). Would bilinguals show any Stroop interference if the printed words are in one language and color naming is performed in another language? The reasoning was that if color naming in language A restricts activation to that lexicon only, then there will be no lexical activation from the printed words in language B, and no interference in color naming should take place. Preston and Lambert (1969), Chen and Ho (1986), and Tzelgov, Henik and Leiser (1990), among others, found that interference does take place when color naming and the printed words were in different languages. This pattern of results held true not only when the two languages shared similar orthographic representations (e.g., Preston and Lambert, 1969, with English–French bilinguals), but also when the orthographies were completely different

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(e.g., Chen and Ho, 1986, with Chinese–English bilinguals). In addition, the results of the bilingual Stroop task suggested that level of proficiency in a second language influences the patterns of interference. With proficient bilinguals, for example, color-naming interference was greater in the within-language condition than in the between-language condition (e.g., Chen and Ho, 1986; Preston and Lambert, 1969; Dyer, 1971; Tzelgov et al., 1990). In general, though, cross-linguistic interference in the bilingual Stroop task is by now a well-established, frequently replicated phenomenon, and has generally been used to counter the selective processing account and to suggest that a bilingual's two lexicons can be activated virtually at the same time. The main problem with convincingly challenging the selective processing account based on Stroop results alone is that the nature of the Stroop task requires that input and output are provided in both languages, leading to overt activation of both L1 and L2. One could then argue that the task demands artificially lead to between-language interference, when, under natural circumstances, parallel activation of both languages may not take place.

Another set of studies, also using written language materials, looked at cross-linguistic lexical interference in priming tasks. An example of such research is Beauvillain and Grainger's (1987) study using French–English homographs, such as COIN, which in French means "corner". French–English bilinguals were presented with such homographs embedded in a list of words in one language and then performed a lexical decision task in the other language (i.e., would the word COIN presented within the French list prime lexical decision for the English word MONEY?). The results indicated that at the 150-ms SOA (Stimulus Onset Asynchrony), facilitation across languages was obtained for test words related to the inappropriate reading of the homograph context words, but at the 750-ms SOA there was no evidence of a facilitation effect. These results led Beauvillain and Grainger to conclude that orthographic input simultaneously activates lexical items across the two lexicons in the very early stages of processing, but this activation later disappears. In a second experiment, Beauvillain and Grainger (1987) found that the facilitation effects were a function of the homograph's relative frequency in the two languages. For example, FOUR is a high frequency word in English and a low frequency word in French ("oven"), while PAIN is of higher frequency in French ("bread") than in English. The facilitation effect for words like FOUR was found to be greater from French into English than from English into French and the facilitation effect for words like PAIN was found to be greater from English into French than from French into English. This led the authors to conclude that word frequency, rather than language, determines which lexical entries are accessed, supporting the position that initial access in bilingual visual word recognition is language-independent. Beauvillain (1992) argues that bilingual visual word recognition is based on a stimulus-driven analysis which is indifferent to language, that lexical representation in bilingual visual word recognition is governed by orthography rather than by language, and that before associating a lexical representation to a stimulus, the subset of entries will be composed of words of one or both languages as a function of the orthographic properties of the input.

Similarly, Grainger and Dijkstra (1992) proposed that lexical representations that share orthographic information with the stimulus are simultaneously activated, independently of which language they belong to. They suggested that a given letter string will simultaneously activate all lexical representations from both languages that share letters with the stimulus and that this simultaneous activation of lexical representations across languages in initial stages of visual word recognition can account for both within- and between-language interference effects. Consistent with the hypothesis of initial language-independent lexical activation is Grainger's (1993) suggestion that external language context information, indicating what language words are likely to belong to, partially influences the way bilinguals recognize printed words in one or the other of their languages and that this information is being used by bilinguals to facilitate the visual word recognition process. However, the non-target lexical system is always operational to a certain extent, giving rise to between-language interference effects.

Recently, it has been suggested (Li, 1996; Grosjean, 1997) that selective activation is less plausible than an activation mechanism that can simultaneously keep both languages on, perhaps to different degrees in different bilingual situations. The results yielded by the experiments reviewed so far do show that both lexicons can be active at the same time when there is lexical input from both languages. However, they do not demonstrate that both lexicons are active at the same time when there is no external activation of the second language. In all the studies reviewed so far, the nature of the experimental task required that both languages were active, as discussed previously by Grosjean (1997, 1998). For example, if priming took place in one language, and the target was presented in the other language, there was direct lexical input from both languages during the experiment. So, in a sense, there is no reason to deactivate one of the languages even if selective activation was possible. The interesting question is: what happens when no input from the other language is presented at all?

Some evidence for parallel activation of both lexicons when no input from the other language is presented comes from experiments using cognates, i.e. words that are identical in two languages at both the graphemic and semantic levels (e.g., de Groot and Nas, 1991; de Groot, 1992, 1993, 1995; van Hell and de Groot, 1998). Studies with cognates demonstrate that cognate processing by bilinguals is slower than that by monolinguals precisely because the second lexicon is also being searched, even in a monolingual condition.

Applicable beyond cognates, which are the exception rather than the rule in bilingualism, are the results of a study by Bijeljac-Babic, Biardeau and Grainger (1997). They investigated activation of orthographic representations in bilingual visual word recognition by using a masked priming paradigm, where the prime was presented for only 57 milliseconds (not long enough to be reportable by subjects). Orthographic priming was observed in both monolingual and bilingual conditions, suggesting that printed strings of letters can simultaneously activate lexical representations in both languages (insofar as these share the same alphabet), even when subjects are performing in a seemingly monolingual task. Nevertheless, it is possible that presenting the prime for 57 milliseconds may be enough to inadvertently activate the other language. What is required then is a study in which activation of the other language can be tested without any overt input or output in that language. But how could activation of a language be measured if that language is never actually used? This goal, in fact, was accomplished by two different paradigms, one used for written language comprehension, and the other used for spoken language comprehension.

The research suggesting parallel processing of the two languages during VISUAL word recognition was conducted by van Heuven and his colleagues, who examined word recognition using the interlingual neighbors paradigm (van Heuven, Dijkstra and Grainger, 1998). Cross-language interference on target word recognition was examined with a comprehensive corpus of Dutch and English words by varying the number of orthographic neighbors of the target word in the non-target language. An orthographic neighbor is any word differing by a single letter from the target word. The results showed that second-language words with a greater number of orthographic neighbors in the first language had slower response times than words that had fewer orthographic neighbors in the first language. In addition, an increase in orthographic neighbors within the same language consistently produced inhibitory effects for the other language and facilitatory effects for the target language. These results from visual word recognition provide compelling evidence for parallel activation of words from a bilingual's two languages.

Research suggesting parallel processing of the two languages during SPOKEN word recognition in bilinguals was conducted using an eye-tracking paradigm (Spivey and Marian, 1999; Marian, 2000; Marian and Spivey, 2003). Previously, for spoken language processing, evidence for parallel activation of both lexicons has been scarce. The headband-mounted eye-tracking methodology (Tanenhaus, Spivey-Knowlton, Eberhard and Sedivy, 1995), used earlier in language processing research with monolingual speakers, made it possible to test language activation using a combination of visual and linguistic input. This work has demonstrated that, when processing a target item in one language (e.g., hearing the word "*can*dle"), monolinguals will often make brief eye movements to another object whose name bears phonological similarity to the target item (e.g., "*can*dy") (Tanenhaus et al., 1995; Allopenna, Magnuson and Tanenhaus, 1998; Spivey-Knowlton, Tanenhaus, Eberhard and Sedivy, 1998; Magnuson, Tanenhaus, Aslin and Dahan, 1999). This suggests that, as the target word unfolds in real time, both "candle" and "candy" are activated in parallel during monolingual language processing. (For a complete review discussing the validity and reliability of the eye-tracking methodology and demonstrating that the tracking of particular objects reflects language activation, see Tanenhaus, Magnuson, Dahan and Chambers, 2000.)

Adapted to be used with bilinguals, eye-tracking allowed indexing the activation of a lexical item in one language without overt use of that language at any point during the experiment. For example, Russian–English bilinguals were presented with a display containing four objects (actual objects or toy replicas, as applicable), a *sha*rk, a balloon ("*sha*rik" in Russian), a horse, and a napkin, and were instructed in English to "pick up the shark". In this case, the Russian word *sharik* was a cross-linguistic COHORT of the English target word *shark* (cf. Marslen-Wilson, 1987; see also Cutler, 1995), i.e., the beginning portion of the name of the target object bore phonological similarity to the name of one of the other objects in the other language. It was found that, when instructed to pick up an object whose name in language A was initially phonologically similar to the name of another object in language B, bilingual subjects frequently looked at the cross-linguistic cohort, even when the other language was not being used overtly (Spivey and Marian, 1999; Marian and Spivey, 2003). This result indicated some overlap in the processing of the two languages in bilinguals, and it was concluded that spoken language automatically activates both mental lexicons in parallel (but one of them only partially because the mapping has only a partial match). However, it is possible that the magnitude of this between-language competition effect may vary across first and second languages, as well as across different language backgrounds, and different stimulus sets.

A potential confound in this work is the participants' language mode at the time of testing. Language mode is defined as "the state of activation of the bilingual's

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languages and language processing mechanisms at a given point in time" (Grosjean, 2001, p. 3). According to the language mode hypothesis, a bilingual's language mode is a continuum ranging from a monolingual language mode, through an intermediate language mode, to a bilingual language mode, depending upon the activation levels of a bilingual's two languages. Grosjean listed a number of variables that may influence a bilingual's position on the language mode continuum, including the interlocutor(s), the situation, the form and content of the message, the function of the language act, and specific research factors, if applicable (Grosjean, 2001, p. 5).

In light of the language mode hypotheses, it is fair to say that the bilinguals tested in the earlier eye-tracking studies (e.g., Spivey and Marian, 1999; Marian and Spivey, 2003) were closer to an intermediate language mode on the language mode continuum, than to a monolingual language mode. Although in that earlier work the base language (language in which communication took place) was either L1 or L2 (e.g., no code-switching took place), a number of factors may have moved the participants in those studies away from the monolingual end of the continuum. For example, participants knew that they were participating in an experiment on bilingualism, they were tested by bilingual experimenters fluent in both languages, and both languages were tested in adjacent experimental sessions. These are among the factors discussed by Grosjean as variables that influence a bilingual's position on the language mode continuum (e.g., simply knowing that the person with whom an exchange takes place is bilingual may influence the activation levels). In experimental situations, knowing that one is taking part in a study of bilingualism may be sufficient reason to maintain both languages active. Failure to instill a monolingual language mode in experiments testing parallel activation of the two languages in bilinguals has frequently been used as criticism of parallel activation studies in both the visual and the auditory domains.

Therefore, the goal of the present work was to control for language mode – a factor suggested to play an important role in bilingual lexical activation – as carefully as reasonably possible. The latter caveat is added because it remains unclear whether bilinguals can ever really reach an entirely monolingual language mode. Grosjean (2001, p. 7) writes: "... it is proposed that the other language is probably never totally deactivated at the monolingual end and that it very rarely reaches the same level of activation as the base language at the bilingual end". Multiple factors, both external and internal, may influence the levels of activation of one's languages, in both bottom-up and top-down ways. For example, in our paradigm the phonological overlap between stimuli may itself activate the other language system in a bottom-up way. Simply having objects in the environment whose names in one language share phonological segments with some of the words being spoken in another language is probably a naturalistic situation that may be unavoidable in the real world. In fact, if all the factors considered to influence a bilingual's language mode are taken into account, it is unlikely that a bilingual ever really reaches a monolingual mode, at least with regard to comprehension.

Experiment 1 aimed to place bilinguals close to the monolingual SECOND-language mode and Experiment 2 aimed to place bilinguals close to the monolingual FIRST-language mode. Participants were tested in one language only, with no code-switching, no mention of the other language and no reference to the relevance of bilingualism to the experiments. Monolingual speakers were used to record the stimuli. Monolingual English speaking experimenters were used to test participants in Experiment 1. In fact, participants in Experiment 1 did not know they were selected to participate in this research because they were bilingual, and believed that they were contacted at random to participate in a study in the Human Information Integration Laboratory. In Experiment 2, different participants were tested, and different experimenters ran the study, this time in Russian. The experimenters posed as monolingual Russian speakers. However, in this second experiment, the subjects were aware that their knowledge of both Russian and English was known to the experimenters (since they were being tested at an American university). For an exact mirror study of Experiment 1, one would have to test bilingual subjects in their home country (in this case Russia) without them knowing that the experimenters were aware of their knowledge of English. Nevertheless, participants in Experiment 1 are as close to a monolingual SECOND language mode as bilinguals may ever get, and participants in Experiment 2 are as close to a monolingual FIRST-language mode as possible given the environment of a different language-speaking country. Together, these experiments test between-language, within-language, and simultaneous competition from both languages in bilingual spoken language processing.

Experiment 1

The objectives of this experiment were to test between-language competition from the first language into the second language, to test within-language competition in the second language, and to test simultaneous between- and within-language competition from both languages into the second language, while placing participants as close to a monolingual second-language mode as possible. The study was conducted exclusively in English, no use of or reference to Russian was made at any point. The design of the study included a control condition where no competitor object was present, a between-language competition condition where a Russian competitor object

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was present, a within-language competition condition where an English competitor object was present, and a simultaneous competition condition where both Russian and English competitor objects were present.

Method

Participants

Fourteen participants, nine males and five females, were tested. The mean age of participants at the time of testing was 20 years. Participants' native language was Russian; their mean age at the time of immigration to the United States was 13. Originally from the Western part of former Soviet Union (Russia, Byelorussia, Ukraine, and Moldova), all participants used standard Russian vocabulary and were familiar with all the lexical items used in the experiment. All participants were full-time university students, none were enrolled in the English-as-a-Second-Language program or in intensive English courses. All participants have had to receive high scores on the SAT college-entrance exam in order to gain admission to a premier American university, and thus were highly proficient and fluent in English, often speaking it without detectable accent. At the time of testing, participants estimated that their use of Russian was limited to an average of about one hour per day (primarily when speaking with family and friends), with English used the rest of the time. When asked after the experiment, four of the participants indicated that Russian was their preferred language of use, eight indicated that English was their preferred language, and two indicated no language preference. All participants were paid for their participation. Appendix 1 reports language history data for each participant. The linguistic background of the bilinguals who participated in the present study is similar to that of the bilinguals tested by Spivey and Marian (1999).

Apparatus

A headband-mounted ISCAN eyetracker was used to record the participants' eye movements during the experiment. The eye-tracker contained two cameras. A scene camera, yoked with the view of the tracked eye, provided an image of the participant's field of view. An eye camera provided an infrared image of the left eye and tracked the center of the pupil and the corneal reflection. The outputs generated by the two cameras were superimposed and were recorded onto a Hi8 VCR with frame-by-frame audio/video playback. Gaze position was indicated by crosshairs superimposed over the image generated by the scene camera. Gaze position was accurate to 0.5 degrees of visual angle.

A naturalistic display of objects was used (as opposed to computer presentation) to increase the ecological validity of the study. Real objects, miniature replicas, or toy replicas were used as applicable. All objects were placed on a white board set on a table. The board was 61 cm × 61 cm and, from the perspective of the subject, spanned about 35 degrees of visual angle horizontally and 30 degrees vertically. It was divided into nine equal squares, with one object presented in each corner square. Eye movements that entered the square in which a relevant object was located were coded as fixations of that object.

Design

The experiment included four conditions, a no-competition control condition, a between-language competition condition, a within-language competition condition, and a simultaneous competition condition. Each target object was used in all four conditions.

In the no-competition control condition, one of the four objects presented in the display was the target object and the other three were control filler objects. The target object was the object actively named in the critical instruction. The filler objects were objects whose name did not overlap with the name of the target object in either language. This first condition served as the baseline for all analyses.

In the between-language competition condition, one of the four objects presented in the display was the target object, one was the between-language competitor, and two were filler objects. The between-language competitor was an object whose name in Russian carried phonological overlap with the English name of the target object. The name of the between-language competitor was never spoken in either language during the experiment. The proportion of eye movements made to the between-language competitor was compared to the proportion of eye movements to a non-overlapping filler object in the same position in the baseline condition. It was important to compare looks to an object in the same position on the display in the control no-competition condition in order to avoid a potential confound – the preference for a particular location in space or movement trajectory during the visual search.

In the within-language competitor condition, one of the four objects presented in the display was the target object, one was the within-language competitor, and two were filler objects. The within-language competitor was an object whose English name carried phonological similarity to the English name of the target object. The name of the within-language competitor was never spoken in either language during the experiment. The proportion of eye movements made to the within-language competitor was compared to the proportion of eye movements to a non-overlapping filler object in the same position in the baseline condition.

Finally, in the fourth condition, one of the four objects presented in the display was the target object, one was a between-language competitor, one was a within-language competitor, and one was a filler object. This fourth condition allowed testing a situation in which simultaneous between-language and within-language competition takes place. The proportion of eye movements made to the between-language competitor was compared to the proportion of eye movements to the non-overlapping filler object in the same position in the baseline condition and the proportion of eye movements made to the within-language competitor was compared to the proportion of eye movements to the non-overlapping filler object in the same position in the baseline condition.

Participants' eye movements were recorded during 40 trials: 10 control trials, 10 between-language competition trials, 10 within-language competition trials, and 10 simultaneous between- and within-language competition trials. The order of the trials was mixed pseudo-randomly, so that no target or competitor was allowed to appear twice consecutively. Each of the 40 trials consisted of four sets of instructions: (1) look at the central cross, (2) pick up the target object, (3) pick up a filler object, and (4) pick up another filler object in the display. In the simultaneous competition condition, where only one filler object was used, the same filler object was manipulated in both the third and the fourth instruction sets. All four conditions of each target set were run for each subject. Thus, similar to previous studies (Allopenna et al., 1998; Spivey-Knowlton et al., 1998), participants were instructed to pick up each target object four times (out of 120 "pick up" instructions), and saw each competitor object twice.

Stimuli

Ten sets of stimuli were selected. Each set consisted of three objects: a target object, a competitor object whose name in English overlapped with the English name of the target object, and a competitor object whose name in Russian overlapped with the English name of the target object. For example, if the target object was "plug", the within-language English competitor was "plum", and the between-language Russian competitor was "plat'e" ("dress"). The following 10 sets of stimuli were used in the experiment (the Russian transliterations were done following the American Library of Congress Transliteration Schemes for Non-Roman Scripts (1991)): (1) speaker—spear—spichki (matches), (2) plug—plum—plat'e ("dress"), (3) card—car—kartoshka ("potato"), (4) gun—gum—gaika ("nut"), (5) chess set—chair—cherepakha ("turtle"), (6) bark—barbed wire—baran ("ram"), (7) boot—book—buben ("tambourine"), (8) shovel—shark—sharik ("balloon"), (9) peace sign—peanuts—pilka ("nailfile"), (10) glove—glass—glaz ("eye"). Objects were either actual artifacts (e.g., nut) or toy replicas (e.g., train). All selected stimulus words are standard words in both languages and are not specific to a particular region. All participants were familiar with the vocabulary used and did not have difficulties understanding any of the words. Item analyses did not reveal any of the stimulus words to produce unusual patterns of looks.

It must be said that the number of phonologically overlapping object names across languages is quite limited. This number becomes minuscule when the list of items is reduced to objects that can be manually manipulated (e.g., must be a noun, concrete rather than abstract, of suitable size to be placed on a table and moved around, etc.). Consider also that all items must be relatively comparable between and within languages in visual attractiveness and relative size. Once all these are considered, there is little choice for competitor sets with respect to word frequencies. All efforts were made to select sets of items that are of comparable frequency in both languages. Given the number of criteria to be considered and the very limited range of word set options, the final stimuli selected were deemed to be the best possible options available across the two languages.

All stimuli were carefully selected, so that the amount of phonological overlap between languages was approximately equal to the amount of phonological overlap within languages, following the International Phonetic Alphabet. In addition, the amount of feature overlap between target and competitor items was computed by calculating the number of phonetic feature similarities between items at onset. Overlap of phonetic features for consonants was judged on four parameters – place of articulation, manner of articulation, voicing, and palatalization. Overlap of phonetic features for vowels was judged on three parameters – vowel height, frontness, and tenseness. Within language, the mean number of overlapping phonemes at onset for the target and within-language competitor was 2.1 phonemes and the mean number of overlapping features was 8.8 features. Between languages, the mean number of overlapping phonemes at onset for the target and between-language competitor was 1.9 phonemes and the mean number of overlapping features was 8.7 features. Table 1 provides IPA phonetic transcriptions for each set of stimuli. Phonemic and featural overlap within and between languages was analyzed based on the number of overlapping phonemes and features, and the results of these analyses are presented in Appendix 2. Results suggest no significant differences in amount of phonemic or featural overlap either between or within languages.

In addition, the average word frequencies of the target word, the between-language competitor and its corresponding filler, the within-language competitor and its corresponding filler, and the other filler in the display were computed, as indexed by three different word frequency sources. For English, we used Zeno, Ivens, Millard & Duvvuri's (1995) word frequency guide, based

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Table 1. *Phonemic transcriptions of stimuli used in Experiment 1 and amount of phonemic and feature overlap between target and competitor items, following International Phonetic Alphabet transcriptions (the accent ` indicates affricate overlap).*

English target	Russian competitor			English competitor		
	Item	Number of phonemes shared at onset	Number of features shared at onset	Item	Number of phonemes shared at onset	Number of features shared at onset
1. Speaker [spikəɹ]	Спички [spitʃki]	3	11	Spear [spiɹ]	3	11
2. Plug [plʌg]	Платье [platjɛ]	2	10	Plum [plʌm]	3	11
3. Card [kaɹd]	Картошка [kartoʃkə]	2	14	Car [kaɹ]	3	11
4. Gun [gʌn]	Гайка [gajkə]	1	6	Gum [gʌm]	2	10
5. Chess set [tʃɛs sɛt]	Черепаха [tʃʲɛrʲɛpahə]	2`	6	Chair [tʃeɹ]	1`	6
6. Bark [baɹk]	Баран [baran]	2	10	Barbed wire [baɹbd waiɹ]	3	11
7. Boot [but]	Бубен [bubʲɛn]	2	7	Book [bʊk]	1	6
8. Shovel [ʃʌvl]	Шарик [ʃarik]	1	6	Shark [ʃaɹk]	1	6
9. Peace sign [pis sain]	Пилка [pilkə]	2	7	Peanuts [pinəts]	2	7
10. Glove [glʌv]	Глаз [glas]	2	10	Glass [glæs]	2	9
Mean		1.90	8.70		2.10	8.8
SD		0.57	2.71		0.88	2.30

on a corpus of 17,274,580 word tokens.[1] For Russian, we used Lenngren's (1993) frequency dictionary based on a corpus of 1,000,000 word tokens, as well as Zasorina's (1977) frequency dictionary based on 40,000 word tokens. In addition, we translated all Russian words used into English and considered the frequency of the translated words in the English language, and translated all the English words used into Russian and considered the frequency of the translated words in the Russian language. Word frequencies (per million) according to the three sources for all the stimuli used (target, between-language competitors and corresponding fillers, within-language competitors and corresponding fillers and the non-competing fillers) and their corresponding translations in the other language are reported in Appendices 3A and 3B, respectively. Mean frequencies across conditions are comparable. (One outlier, *glaz* (Russian for "eye"), is unusually frequent because it is used in many Russian idioms.) Frequency analyses were performed using independent samples t-tests. Because numerous comparisons were performed to account for all variables (type of competition – within vs. between, item status – target vs. competitor vs. matching filler vs. filler – language – original or translation – and frequency source – 2 sources for Russian), and because none of the tests produced significant results, only the most relevant comparisons are reported in Appendix 2. In addition, subsequent item analyses did not reveal any differences among individual item groups.

Procedure

A monolingual English speaker was used for the recording of the instructions to manipulate objects. This was done to avoid any possible detection of bilinguality in the speaker, conscious or unconscious, and to ensure a monolingual language mode.

Participants were contacted after they had already been independently identified as fitting the criteria for testing and no mention of the bilingual nature of the study was ever made to them. They were contacted by phone by monolingual English speakers and told that their name was selected at random from the university directory and that they were invited to participate in a paid experiment examining eye movements while following simple commands. No emphasis on language as the subject of the experiment was made. All subjects were tested by English-speaking research assistants who did not know Russian. All participants were tested in one language only, English. Russian was never used during the experiment, nor was their knowledge of another language mentioned at any point during the study. However, after

[1] Zeno's et al. 1995 frequency norms were used because they are more recent than Francis and Kucera (1982). The CELEX database was not available to us at the time.

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Table 2. *Percent of trials in which bilingual participants made eye movements to the competitor items and their corresponding fillers in between-language competition, within-language competition, and simultaneous competition trials in Experiment 1.*

Display	Fixations of between-language competitor	Fixations of within-language competitor
Between-language competitor present	18%	n/a
Within-language competitor present	n/a	18%
Both competitors present	13%	19%
No competitor present; fixations of control filler object	7%	

all data were collected and the session was completed, participants were questioned about their hypothesis of the experiment and were asked to fill out a language history questionnaire.

Results

Trials were coded as containing zero or greater-than-zero fixations of the between-language competitor object (if it was present), the within-language competitor object (if it was present), and their associated filler (control) objects in those same squares. Analyses of variance were performed on each of the three different types of competition and the results are reported in Table 2. During between-language competition trials, participants looked at the between-language Russian competitor on 18% of the trials and at the non-overlapping control filler in the same location (in control trials) on 7% of the trials, suggesting that bilinguals experience competition from the first language into the second language. This difference was statistically significant in the by-subjects analyses, $F1\ (1, 13) = 10.448$, $p < 0.01$, and did not quite reach significance in the by-items analyses, $F2\ (1, 9) = 4.625$, $p = 0.06$.

During within-language competition trials, participants looked at the within-language English competitor on 18% of the trials and at the non-overlapping control filler in the same location (in control trials) on 7% of the trials, showing consistent within-language competition from phonologically overlapping items during second-language processing. This difference was statistically significant in both by-subjects and by-items analyses: $F1\ (1, 13) = 5.201$, $p < 0.05$; $F2\ (1, 9) = 11.906$, $p < 0.01$.

For simultaneous competition from both between- and within-languages, a two-way ANOVA with Type of Competition (Between or Within) and Condition (Competitor or Filler) was performed. The results revealed a main effect of condition, with subjects making eye movements to overlapping competitors on 16% of the trials and to non-competing control fillers in the same location on 7% of the trials. This difference was significant both by subjects, $F1\ (1, 13) = 7.875$, $p < 0.05$, and by items, $F2\ (1, 9) = 22.661$, $p < 0.01$. No effect of Type of Competition and no interaction between variables were observed. Participants made eye movements to the within-language competitor in 19% of all trials and to the between-language competitor in 13% of all trials. Of course, some individual trials involved the subject's eyes briefly fixating both competitors before finally resting on the spoken target object. These results suggest that during simultaneous competition from both languages, bilinguals may experience competing activation from phonologically overlapping items within as well as between languages.

Discussion

The results of Experiment 1 show that bilinguals experience between-language competition from their first into their second language, as well as within-language competition in their second language. In situations of simultaneous competition, phonologically overlapping items appear to compete both between and within languages. Tested by monolingual speakers, in a monolingual environment, without any knowledge on the participants' part of the relevance of Russian or bilingualism to the experiment, this study tests bilingual spoken language processing in a language mode that is as close to monolingual as possible. Even under such rigorously controlled circumstances, the hypothesis of parallel activation of both languages was supported.

Experiment 2

The objectives of this experiment were to test between-language competition from the second language into the first language, to test within-language competition in the first language, and to test simultaneous between- and within-language competition from both languages into the first language, while maintaining the language mode as close to monolingual first-language as possible. No use of the second language was made at any time during the study. In fact, the subjects were led to believe that the experimenters were monolingual Russian speakers. Although the language mode in this experiment is more

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monolingual than in Spivey and Marian (1999) and Marian and Spivey (2003), it is likely less monolingual than the language mode of Experiment 1. Participants in Experiment 2 knew the experimenters were aware of their bilingualism (Russian was the language of the experiment and English was the language in which they were studying at the university). They may have also detected (consciously or not) the bilingual status of the experimenters, in spite of the disguise (or may have failed to believe their monolingual status in the first place – although no evidence for that surfaced, the possibility must be allowed). Nevertheless, an advantage of this study is that subjects were never tested in English, nor did their command of English seem relevant to the study. In addition, a monolingual Russian speaker was used to record the instructions for this experiment.

Method

Participants

Fourteen participants, eight males and six females, were tested in this experiment; none of them participated in Experiment 1. The mean age of the participants at the time of testing was 21 years. Their mean age of immigration to the United States was 15. When asked after the experiment, four of the participants indicated that Russian was their preferred language of use, eight indicated that English was their preferred language, and two indicated no language preference. All participants were full-time students at a premier American university, and were similar in their linguistic background to the participants tested in Experiment 1 and in Spivey and Marian (1999). At the time of testing, participants estimated that their use of Russian was limited to an average of about one hour per day (primarily when speaking with family and friends), with English used the rest of the time. Data from another subject was discarded due to the fact that he noticed the phonological overlap in some of the stimuli sets. All participants were paid for their participation. Appendix 4 indicates language history data for each participant.

Stimuli

Ten sets of stimuli were selected. Each set consisted of three objects: a target object, a competitor object whose name in Russian overlapped with the Russian name of the target object, and a competitor object whose name in English overlapped with the Russian name of the target object. For example, if the target object was *sharik* ("balloon"), the within-language Russian competitor was *shapka* ("hat"), and the between-language English competitor was *shark*. The ten stimulus sets selected were: (1) barkhat (velvet)—baran ("ram")—barbed wire, (2) plat'e ("dress")—plashch ("raincoat")—plug, (3) gaika ("nut")—galstuk ("tie")—gun, (4) karta ("map")—kartoshka ("potato")—card, (5) cherepakha ("turtle")—cherep ("skull")—chair, (6) busy ("necklace")—buben ("tambourine")—book, (7) spitsy ("knitting needles")—spichki ("matches")—spear, (8) sharik ("balloon")—shapka ("hat")—shark, (9) marka ("stamp")—morkov' ("carrot")—marker, (10) flakonchik ("perfume bottle")—flomaster ("marker")—flower. The Russian transliterations were done following the American Library of Congress Transliteration Schemes for Non-Roman Scripts (1991). All participants were familiar with the vocabulary used and did not have difficulties understanding any of the words. Item analyses did not reveal any of the stimulus words to produce unusual patterns of looks.

All stimuli were carefully selected, so that the amount of phonological overlap between languages was approximately equal to the amount of phonological overlap within languages (see Table 3). Within language, the mean number of overlapping phonemes at onset for the target and within-language competitor was 3 phonemes and the mean number of overlapping features was 11.3 features. Between languages, the mean number of overlapping phonemes at onset for the target and between-language competitor was 1.9 phonemes and the mean number of overlapping features was 10 features. Table 3 provides IPA phonetic transcriptions for each set of stimuli, as well as the amount of phonemic and featural overlap. Phonemic and featural overlap within and between languages were compared and the results are reported in Appendix 5. Amount of feature overlap at onset did not differ between and within languages. Amount of phonemic overlap suggests that more phonemes overlapped within languages than between languages ($t(9) = 2.91$, $p < 0.05$).

In addition, the average word frequencies of the Russian targets, the between-language competitors and their corresponding fillers, the within-language competitors and their corresponding fillers, and the remaining fillers in the display were computed once again using the three word frequency sources as described in Experiment 1 (Zasorina, 1977; Lenngren, 1993; Zeno et al., 1995). Appendix 6 (6A and 6B) reports individual frequencies (per million) and means for items in each condition and also includes the frequency of items when translated in the other language (e.g., frequency of the English translation of a Russian target word). None of the performed analyses showed any statistically significant differences in word frequencies. Results of the most relevant comparisons are reported in Appendix 5. Mean frequencies across conditions are comparable. Subsequent item analyses did not reveal any differences in the pattern of looks for individual item groups.

As in Experiment 1, only items that adhered to the following criteria were included: must be a noun, must be concrete rather than abstract, must be of suitable size to be placed on a table and moved around, must represent a

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Table 3. *Phonemic transcriptions of stimuli used in Experiment 2 and amount of phonemic and feature overlap between target and competitor items, following International Phonetic Alphabet transcriptions (the accent ` indicates affricate overlap).*

Russian target	English competitor			Russian competitor		
	Item	Number of phonemes shared at onset	Number of features shared at onset	Item	Number of phonemes shared at onset	Number of features shared at onset
1. Бархат [bɑɹhət]	Barbed wire [bɑɹbd waiɹ]	2	10	Баран [bɑrɑn]	3	11
2. Плащ [plɑç]	Plug [plʌg]	2	10	Платье [plɑtjɛ]	3	11
3. Гайка [gɑjkə]	Gun [gʌn]	1	6	Галстук [gɑlstək]	2	7
4. Карта [kɑrtə]	Card [kɑɹd]	2	14	Картошка [kɑrtoʃkə]	3	15
5. Черепаха [tʃʲɛrʲɛpɑhə]	Chair [tʃeɹ]	1`	8	Череп [tʃʲɛrʲɛp]	5`	18
6. Бусы [busɨ]	Book [bʊk]	1	6	Бубен [bubʲɛn]	2	7
7. Спицы [spitsɨ]	Spear [spiɹ]	3	11	Спички [spitʃki]	3	11
8. Шарик [ʃɑrik]	Shark [ʃɑɹk]	2	10	Шапка [ʃɑpkə]	2	7
9. Марка [mɑrkə]	Marker [mɑɹkəɹ]	2	14	Морковь [mɑrkovʲ]	4	15
10. Флакончик [flɑkontʃik]	Flower [flɑuəɹ]	3	11	Фломастер [flɑmasʲtɛr]	3	11
Mean		1.90	10		3.0	11.3
SD		0.74	2.79		0.94	3.77

clear exemplar, must be accessible either by purchase or by construction, must be of comparable size to other items in the display, must be of comparable frequency across languages, must be of comparable frequency across conditions, and must not be colloquially specific to a particular region. Whenever possible, we also tried to avoid items belonging to the same semantic category (with the exception of one within-language Russian competition set, 'dress' and 'raincoat'). All efforts were made to choose the sets that fit best all of these criteria.

Procedure

The same eye-tracking equipment, design and methodology were used as in Experiment 1. The recording of the instructions was made using a monolingual speaker. The speaker was a Russian student who had arrived to the U.S. the previous week to study English in an intensive English program and did not study or know any English prior to her arrival.

Participants were contacted by phone, in Russian, and were asked to participate in a study of Russian language speakers, and were offered monetary compensation for their participation. During the experiment, they were tested by bilingual Russian-English speakers who posed as newcomers from Russia who did not speak English. All participants were tested in Russian only. English was never used during the experiment, nor was their knowledge of another language mentioned at any point during the study. After all data were collected and the session was completed, participants were questioned about their hypothesis of the experiment, and were also asked to fill out a language history questionnaire.

As in Experiment 1, eye movements were recorded during 40 trials: 10 control trials, 10 between-language competition trials, 10 within-language competition trials, and 10 simultaneous between- and within- language competition trials. The order of the trials was mixed pseudo-randomly, with no target or competitor appearing twice consecutively. Each of the 40 trials consisted of 4 sets of instructions: (1) look at the central cross, (2) pick up the target object, (3) pick up a filler object, and (4) pick up another filler object in the display. In the simultaneous competition condition, where only one filler object was used, the same filler object was manipulated in both the third and the fourth instruction sets.

Results

Trials were coded as containing zero or greater-than-zero fixations of the between-language competitor object (if it was present), the within-language competitor object (if it was present), and their associated filler (control) objects in those same squares. Experiment 2 data were analyzed using analyses of variance and the results are reported in Table 4. During between-language competition trials,

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Table 4. *Percent of trials in which bilingual participants made eye movements to the competitor items and their corresponding fillers in between-language competition, within-language competition, and simultaneous competition trials in Experiment 2.*

Display	Fixations of between-language competitor	Fixations of within-language competitor
Between-language competitor present	8%	n/a
Within-language competitor present	n/a	14%
Both competitors present	8%	13%
No competitor present; fixations of control filler object	5%	

participants looked at the between-language English competitor on 8% of the trials and at the non-overlapping control filler in the same location (in control trials) on 5% of the trials. This difference was not significant either by subjects [$F1\ (1, 13) = 0.525$, N.S.] or by items [$F2\ (1, 9) = 1.107$, N.S.].

During within-language competition trials, participants looked at the within-language Russian competitor on 14% of the trials and at the non-overlapping control filler in the same location (in control trials) on 5% of the trials. This difference was significant by subjects, $F1\ (1, 13) = 4.973$, $p < 0.05$, and did not quite reach significance by items, $F2\ (1, 9) = 4.346$, $p = 0.07$.

For simultaneous competition from both between- and within-languages, a two-way ANOVA with Type of Competition (Between or Within) and Condition (Competitor or Filler) was performed. The results revealed a main effect of condition, with subjects making eye movements to overlapping competitors on 11% of the trials and to non-competing control fillers in the same location on 5% of the trials. This difference was significant only by subjects, $F1\ (1, 13) = 6.196$, $p < 0.05$; $F2\ (1, 9) = 2.742$, N.S. No effect of type of competition and no interaction between the two variables were observed. Participants made eye movements to the within-language competitor in about 13% of all trials and to the between-language competitor in about 8% of all trials. These results suggest that during simultaneous competition from both languages, bilinguals listening to their native language experience competing activation from phonologically overlapping items within that language, but may not experience substantial competing activation from their second language.

Discussion

Experiment 2 tested first-language processing in Russian–English bilinguals who were relatively close to a monolingual first-language mode. On a language mode continuum, the language mode during this experiment may not have been as close to the monolingual end as that of Experiment 1, however it was closer to monolingual than that of Spivey and Marian (1999).

Similar to Experiment 1, participants in Experiment 2 showed within-language competition. In this case the within-language competition takes place in Russian, thus extending the within-language competition phenomena reported earlier in English to a Slavic language. Also replicating the findings of Experiment 1, in the simultaneous competition condition, participants experienced simultaneous competition from both languages (the pattern of results in both experiments suggests a tendency for within-language competition to be stronger than between-language competition). This further supports the parallel activation hypothesis and suggests that bilinguals activate, at least partially, lexical items in both of their lexicons at the same time. We draw these conclusions based on the by-subject analyses as the most appropriate analyses on this type of linguistic data (cf. Raaijmakers, Schrijnemakers and Gremmen, 1999).

Experiment 2 did not reveal a significant difference in the proportion of eye movements to a between-language competitor compared to a non-overlapping control filler. Although the trend of the effect was in the predicted direction, the difference between the proportion of eye movements to competitor versus filler did not reach significance. These results suggest that in this particular experiment the second language did not compete significantly with the first language.

General discussion

The question of whether bilinguals activate their two languages selectively or in parallel has generated much interest in the bilingual research community. More and more recent research has substantiated the parallel access hypothesis (Grainger and Beauvillain, 1987; Beauvillain, 1992; Grainger and Dijkstra, 1992; Grainger, 1993; Li, 1996; Spivey and Marian, 1999; Marian and Spivey, 2003). The present paper provides further evidence for the parallel access position from two eye-tracking experiments examining between-language

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competition, within-language competition, and simultaneous competition from both languages during bilingual spoken language processing in a language mode approaching the monolingual end of the language mode continuum.

The within-language competition effect was observed unequivocally in both experiments. Experiment 1 showed within-language competition in the second language, extending the within-language phenomenon to one's second language. Experiment 2 showed within-language competition in the bilinguals' first language, Russian, extending the within-language phenomenon to a language other than English. Together, the results of the within-language competition analyses establish the phenomenon of within-language competition in bilinguals and replicate the within-language phenomenon observed earlier with monolinguals. Future work may be needed to examine how the level of proficiency in a second language influences within-language competition during second language comprehension. In fact, it is likely that one's fluency in a language will influence the magnitude of competition from lexical items in that language both within and between languages. The present work was performed with late bilinguals who were fluent in both languages. And while it seems reasonable to also extend the argument of parallel activation to early bilinguals (who are likely to show between, within, and simultaneous competition from both languages similar to, if not more than, late bilinguals), the effects of fluency levels and of age of acquisition are important empirical concerns for future investigation.

For the analyses of simultaneous within- and between-language competition, results suggest that bilinguals can experience simultaneous competition from items both between- and within-languages. These results with bilinguals further support the incremental activation accounts of spoken word recognition that have been widely considered for monolinguals (e.g., McClelland and Elman, 1986; Marslen-Wilson, 1987; Cutler, 1995; Allopenna et al., 1998). In the long run, these findings with bilinguals may alter our definition of 'cohorts', especially in relation to bilinguals. In aggregate, these two experiments provide a rigorous test of between-language, within-language, and simultaneous competition from both languages in bilinguals during spoken language comprehension in a monolingual environment. It seems that bilingual lexical access may be language-independent in the initial few hundred milliseconds, but, with time to process context information, inappropriate meanings are inhibited (Beauvillain and Grainger, 1987; see also Swinney, 1979, and Tanenhaus, Leiman and Seidenberg, 1979). This is consistent with the current position in cognitive science that word recognition in general involves a parallel activation mechanism (e.g., McClelland and Elman, 1986; Marslen-Wilson, 1987).

For between-language competition, it is likely that competition is possible from both languages and into both languages (cf. Spivey and Marian, 1999; Marian and Spivey, 2003), but whether or not between-language competition will manifest itself depends upon numerous variables influencing the degree of activation of a language. For example, in the experiments reported here, between-language competition from the first language into the second language was significant, while between-language competition from the second language into the first language did not approach significance. How can one account for these differences? Moreover, how can one reconcile these findings with the results of Spivey and Marian (1999), who reported the opposite pattern? In both experiments described above, as well as in Spivey and Marian (1999), the direction of the effect was the same in both languages (more eye movements to the between-language competitor than to a non-overlapping control filler), but the magnitude of the effect differed and did not always reach significance. It is likely that these differences are due to a combination of factors. In fact, differences in magnitude of between-language competition observed with eye-tracking mirror a pattern of results frequently reported in the bilingualism literature, namely similar experiments resulting in seemingly conflicting results. It has been suggested in the past (e.g., Grosjean, 1998) that variation in selection of participants, stimuli, tasks, models, and language mode may all influence the pattern of results and be responsible for differences in outcomes. Three of these variables – stimulus selection, participant selection, and especially language mode – are directly relevant to explaining the differences in these eye-tracking results.

Consider, for example, language mode. Participants' location on the language mode continuum and the relative activation of the two languages with respect to each other will have a direct effect on the proportion of eye movements made to competing items. We do not yet have sufficient empirical evidence showing exactly how much variation in language mode is enough to drive competition effects, but it is safe to say that differences such as being tested in both languages in the same experimental session by fluent bilingual speakers (as in Spivey and Marian, 1999) will result in participants being in a different language mode than when tested by monolingual speakers in one language only in a study that does not seem related to bilingualism (as in Experiment 1 reported in this paper). Differences in position on the language mode continuum are quite likely to be at least partially responsible for the observed difference in results. It is possible, for example, that motivational factors (such as trying to show, consciously or unconsciously, that one has good command of the second language when participating in a bilingualism experiment – as in Spivey and Marian, 1999) may result in overcompensation, increasing

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the level of activation of that second language and lowering the threshold of activation for second-language competitors. Overcompensation may not come into play when participants are not aware of the bilingual nature of the study and when competence in the second language seems irrelevant (as in Experiment 2 in this paper). Such motivational factors are not an unlikely cause in driving effects in bilingualism research and are even more likely to manifest themselves in the laboratory environment. Similarly, other variables affecting a bilingual's language mode may have influenced the degree of activation of the two languages in relation to one another and future studies would do well to examine specifically the factors affecting a bilingual's language mode and their effect on eye movement patterns in between-language competition.

Next, consider our efforts to control for stimulus differences. Apart from the difficulties in generating stimuli that will satisfy all the criteria as discussed in the methods section, it is important to clearly articulate the effects that stimulus selection may have on the pattern of results. Differences in amount of phonological overlap, word frequencies, size of stimuli, etc. are likely to directly influence the degree of competition. For example, the higher phonological overlap within languages than between languages in Experiment 2 may have contributed to the pattern of results observed in the simultaneous competition condition. Although possibly a confounding factor in this case, the pattern of phonological overlap is unlikely to have influenced the results in a significant way, because (a) a comparison of feature overlap – a more sensitive measure – did not reveal a significant difference; (b) the interaction with type of competition in the two-way ANOVA was not significant; and (c) a similar pattern of results for simultaneous competition was found in Experiment 1 and in Marian and Spivey (2003). In addition to phonological and feature overlap, one might want to take into account the role of syllable overlap and of syllable structure in a more extensive effort to control for confounding variables. Similar arguments can be made for word frequencies. Although the range of word frequencies is relatively limited in the stimuli used (if one considers the possible range of word frequencies), some variations in frequencies are present. It is possible that these variations in frequencies have contributed to the patterns of effects observed, although the large standard deviations led to insignificant differences.

Moreover, the participants studied, although coming from the same population and appearing to have relatively similar linguistic backgrounds and proficiency levels, may have differed on some parameters, such as language dominance, just enough to influence the pattern of results. It is possible and quite likely that the magnitude of the between-language competition effect is influenced by even small differences in language dominance, and future research will need to make a more careful effort at controlling, or manipulating, language dominance in order to measure its effect on between-language competition. It may be that inefficient skill with the second language is responsible for the first language interfering with the second language but not vice versa in the present study (cf. Grosjean, 1998). The combination of inefficient skill in their second language and an environment closer to the monolingual end of the continuum engendered in the experimental sessions of the present study may have enabled participants to inhibit their second language enough for it to not show significant interference with first language comprehension.

In addition to considering proposals that a bilingual's languages can be at different levels of activation and that use of a language is influenced by its activation level (e.g., Grosjean, 1988, 1997, 1998), one could also interpret the results of the present work in terms of David Green's Inhibitory Control model of bilingual language processing (e.g., Green, 1986, 1993, 1998, 2000). Specifically, Green proposes a model based on control, activation and resource, in which activation and control takes place in both bottom-up and top-down ways. The idea that homophonic word onsets activate a bilingual's other language in a bottom-up way is consistent with Green's hypotheses. Within the framework of Green's model, our results can be interpreted to suggest that the other language is not inhibited (although it should be noted that it is not necessary to postulate an inhibition mechanism in order to account for parallel activation in bilingual or monolingual language processing).

For now, it suffices to say that bilinguals can and do experience competition from both languages and into both languages, although the magnitude of the effect changes under different circumstances. For comparison, in our recent work testing monolingual English speakers with the exact same objects and English instructions and under the same experimental conditions, within-language competitor objects were fixated on 20% of the trials, while between-language competitor objects (whose phonologically overlapping Russian names were not known to the participants) were fixated on 5% of the trials, and filler objects were fixated on 8% of the trials (Marian and Spivey, 2003). Future work will examine how phonological overlap interacts with semantic overlap during bilingual language processing by examining bilinguals' eye movements to cognates and non-cognates (Marian and Blumenfeld, in progress).

Any theory aimed at explaining bilingual language processing must be able to take into account the dynamics and changes that take place over time. General theories of language acquisition, representation and processing in monolinguals have already come to this realization some time ago. It would be a mistake to think that the bilingual architecture is in any way less complex, and that there

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are discrete 'yes' or 'no' answers (e.g., to the parallel versus selective processing question). At this point, the issue would benefit greatly from the theoretical precision and explicit predictions of a computational model. Computational models of bilingual language processing are being continuously developed and include the Bilingual Activation Verification model (Grainger, 1993), BIMOLA (Grosjean, 1997), the Bilingual Interactive Activation model (Dijkstra, van Heuven and Grainger, 1998; van Heuven, Dijkstra and Grainger, 1998), SOPHIA (van Heuven, 2000), and the Self-Organizing Model of Bilingual Processing (Li and Farkas, 2002).

Models of spoken language processing in bilinguals are needed to explicitly formulate the hypothesis of parallel activation of two languages quantitatively. However, current models of bilingualism have not yet been aimed at testing competing hypotheses of bilingual lexicon architecture. Does a bilingual have two lexicons that receive simultaneous inputs from a shared acoustic-phonetic array? (In this account, the competition that determines which object gets fixated takes place downstream.) Or does a bilingual have one lexicon, and its partially active lexical items from two different languages directly compete with one another? One way to go about asking this would be to build two different models of parallel language processing in bilinguals – one model would assume two separate lexical stores, one for each language, and the other model would assume a single lexical store for both languages. Both of these models can be designed to accommodate the parallel activation phenomena reported here. However, experimentation with the two models may lead to subtly different empirical predictions. An interchange between computational modeling and empirical research may in the long run provide conclusive answers to many important questions within bilingualism research.

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Appendix 1: ***Demographic data for each participant in Experiment 1.***

Participant number	Gender	Current age (yrs;mos)	Age at immigration (yrs;mos)	Frequency of current L1 use, hours per week	Preferred language
1	F	18;11	14;11	Not available	L1
2	M	24;6	20;4	Not available	L1
3	F	19;6	15;4	1	L1
4	F	19;8	10;11	0.5	L2
5	M	21;3	15;7	21	L1
6	F	20;2	10;6	35	L2
7	M	20;6	13;6	4	No preference
8	M	18;10	10;4	7	L2
9	M	21;9	13	0.5	L2
10	M	21;11	13;9	1.5	L2
11	F	19;11	14	3	L2
12	M	18;6	9;9	2	L2
13	M	20;5	13;9	1	No preference
14	M	17;11	10;9	7	L2
Mean		20;3	13;4	7	
SD		1;8	2;10	10.5	

Appendix 2: ***Results of control comparisons for phonemic overlap, featural overlap, and word frequencies for stimuli items used in Experiment 1.***

Comparison	Means	Analysis	Significance
Number of features that overlapped at onset between targets and between-language competitors TO number of features that overlapped at onset between targets and within-language competitors	8.7 vs. 8.8	$t(18) = 0.09$	N.S.
Number of phonemes that overlapped at onset between targets and between-language competitors TO number of phonemes that overlapped at onset between targets and within-language competitors	1.9 vs. 2.1	$t(18) = 0.61$	N.S.
Frequencies of English targets TO frequencies of corresponding between-language Russian competitors	30 (SD = 25) vs. 174 (SD = 352)	$t(13) = 1.16$	N.S.
Frequencies of English targets TO frequencies of corresponding within-language English competitors	30 (SD = 25) vs. 96 (SD = 117)	$t(15) = 1.65$	N.S.
Frequencies of between-language Russian competitors TO frequencies of within-language English competitors	174 (SD = 352) vs. 96 (SD = 117)	$t(14) = 0.63$	N.S.
Frequencies of within-language English competitors TO frequencies of corresponding filler items	96 (SD = 117) vs. 40 (SD = 32)	$t(15) = 1.31$	N.S.
Frequencies of between-language Russian competitors TO frequencies of corresponding filler items	174 (SD = 352) vs. 51 (SD = 48)	$t(8) = 0.58$	N.S.

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Appendix 3A: ***English word frequencies for target, competitor and filler items used in Experiment 1.***

	English target		Between-language competitor (BLC)				Within-language competitor (WLC)				Filler	
	Target	Frequency	Translation of Russian competitor	Frequency	BLC filler	Frequency	WLC English	Frequency	Filler	Frequency	Non-competing Filler	Frequency
1	Speaker	42	Matches	12	Chess set	n/a	Spear	12	Plate	65	Toothbrush	4
2	Plug	9	Dress	63	Razor	4	Plum	5	Bark	41	Knife	40
3	Card	73	Potato	18	Boot	8	Car	271	Napkin	5	Jar	40
4	Gun	52	Nut	10	Fish	260	Gum	15	Peace sign	n/a	Spoon	13
5	Chess set	n/a	Turtle	25	Fork	16	Chair	95	Glove	7	Light bulb	0.1
6	Bark	41	Ram	6	Toothbrush	4	Barbed wire	n/a	Gun	52	Sponge	11
7	Boot	8	Tambourine	1	Plug	9	Book	301	Hair clip	n/a	Lipstick	2
8	Shovel	10	Balloon	40	Card	73	Shark	16	Train	97	Pencil	16
9	Peace sign	n/a	Nail file	n/a	Dental floss	n/a	Peanuts	11	Speaker	42	Keychain	70
10	Glove	7	Eye	133	Fork	16	Glass	141	Shovel	10	Plate	65
	Mean	30		34		49		96		40		28
	SD	25		42		88		117		32		26

Appendix 3B: ***Russian word frequencies for target, competitor and filler items used in Experiment 1.***

	English target			Between-language competitor (BLC)						Within-language competitor (WLC)						Filler		
		Frequency			Frequency			Frequency			Frequency			Frequency			Frequency	
	Translation of English target	1993	1977	Russian competitor	1993	1977	BLC filler	1993	1977	Russian translation of English competitor	1993	1977	WLC filler	1993	1977	Non-competing filler	1993	1977
1	Колонка	10	4	Спички	32	83	Шахматы	22	8	Копье	21	9	Тарелка	31	48	Зубная щетка	n/a	n/a
2	Вилка	n/a	7	Платье	74	71	Бритва	n/a	7	Слива	n/a	11	Кора	53	43	Нож	72	n/a
3	Отркрытка	25	18	Картошка	68	28	Сапог	106	123	Машинка	12	11	Салфетка	n/a	16	Банка	47	62
4	Пистолет	22	28	Гайка	23	7	Рыбка	n/a	16	Жевательная резинка	n/a	n/a	Знак мира	n/a	n/a	Ложка	34	41
5	Шахматы	22	8	Черепаха	n/a	1	Вилка	n/a	7	Стул	65	98	Перчатка	25	25	Лампочка	23	30
6	Кора	53	43	Баран	20	8	Зубная щетка	n/a	n/a	Колючая проволока	n/a	n/a	Пистолет	22	28	Мочалка	n/a	n/a
7	Сапог	106	123	Бубен	n/a	3	Вилка	n/a	7	Книга	231	691	Заколка	n/a	n/a	Помада	n/a	7
8	Лопата	17	33	Шарик	31	24	Открытка	25	18	Акула	n/a	4	Поезд	67	128	Карандаш	23	75
9	Знак мира	n/a	n/a	Пилка	n/a	1	Зубная нить	n/a	n/a	Орешки	48	2	Колонка	10	4	Брелок	n/a	n/a
10	Перчатка	11	25	Глаз	971	1093	Вилка	n/a	7	Стакан	75	111	Лопата	17	33	Тарелка	31	48
	Mean	33	32		174	132		51	24		75	117		32	41		38	44
	SD	32	37		352	339		48	40		80	236		21	38		19	24

Appendix 4: ***Demographic data for each participant in Experiment 2.***

Participant number	Gender	Current age (yrs;mos)	Age at immigration (yrs;mos)	Frequency of current L1 use, hours per week	Prefered language
1	M	21;4	17;8	7	L2
2	M	18;6	11;2	10.5	L2
3	M	25;10	20;8	5	L1
4	M	28;7	23;6	17.5	No preference
5	M	28;3	23;1	5	L1
6	F	19;4	15;11	14	L1
7	F	20;6	13;5	4.5	L2
8	M	18;4	11;91	17.5	L2
9	M	18;4	13	1	L2
10	M	19;7	14;11	3	L1
11	F	19;4	14;10	7	No preference
12	F	18;10	14;5	2.5	L2
13	F	21;10	11;9	7	L2
14	F	18;7	8;5	3	L2
Mean		21;3	15;3	7.5	
SD		3;8	4;6	5.4	

Appendix 5: ***Results of control comparisons for phonemic overlap, featural overlap, and word frequencies for stimuli items used in Experiment 2.***

Comparison	Means	Analysis	Significance
Number of features that overlapped at onset between targets and between-language competitors TO number of features that overlapped at onset between targets and within-language competitors	10 vs. 11.3	$t(18) = 0.88$	N.S.
Number of phonemes that overlapped at onset between targets and between-language competitors TO number of phonemes that overlapped at onset between targets and within-language competitors	1.9 vs. 3	$t(18) = 2.9$	$p < 0.05$
Frequencies of Russian targets TO frequencies of corresponding between-language English competitors	38 (SD = 26) vs. 68 (SD = 93)	$t(12) = 0.69$	N.S.
Frequencies of Russian targets TO frequencies of corresponding within-language Russian competitors	33 (SD = 26) vs. 38 (SD = 26)	$t(15) = 0.008$	N.S.
Frequencies of between-language English competitors TO frequencies of within-language Russian competitors	38 (SD = 26) vs. 68 (SD = 93)	$t(15) = 0.88$	N.S.
Frequencies of within-language Russian competitors TO frequencies of corresponding filler items	38 (SD = 26) vs. 43 (SD = 30)	$t(11) = 0.33$	N.S.
Frequencies of between-language English competitors TO frequencies of corresponding filler items	68 (SD = 93) vs. 17 (SD = 15)	$t(15) = 1.53$	N.S.

Appendix 6A: ***English word frequencies for target, competitor and Filler items used in Experiment 2.***

	Russian target		Between-language competitor				Within-language competitor				Filler	
	Translation of target	Frequency	English competitor	Frequency	BLC filler	Frequency	Translation of Russian competitor	Frequency	WLC filler	Frequency	Non-competing filler	Frequency
1	Velvet	15	Barbed wire	n/a	Screwdriver	3	Ram	6	Turtle	25	Sponge	11
2	Raincoat	4	Plug	9	Knife	40	Dress	63	Stamp	21	Razor	4
3	Nut	10	Gun	52	Velvet	15	Tie	30	Fish	260	Spoon	13
4	Map	183	Card	73	Overcoat	4	Potato	18	Napkin	5	Jar	39
5	Turtle	25	Chair	95	Fork	16	Skull	20	Knitting needles	n/a	Light bulb	0.1
6	Necklace	5	Book	301	Nut	10	Tambourine	1	Hair clip	n/a	Lipstick	2
7	Knitting needles	n/a	Spear	12	Perfume bottle	n/a	Matches	12	Plate	65	Toothbrush	4
8	Balloon	40	Shark	16	Necklace	5	Hat	80	Train	97	Pencil	36
9	Stamp	21	Marker	4	Dental floss	n/a	Carrot	5	Map	183	Key chain	n/a
10	Perfume bottle	n/a	Flower	47	Balloon	40	Marker	4	Pen	32	Napkin	5
	Mean	38		68		17		24		86		13
	SD	60		93		15		27		91		15

Appendix 6B: ***Russian word frequencies for target, competitor and filler items used in Experiment 2.***

	Russian target			Between-language competitor						Within-language competitor						Filler		
		Frequency			Frequency			Frequency			Frequency			Frequency			Frequency	
	Target	1993	1977	Translation of English competitor	1993	1977	BLC filler	1993	1977	Russian competitor	1993	1977	WLC filler	1993	1977	Non-competing filler	1993	1977
1	Бархат	n/a	15	Колючая проволока	n/a	n/a	Отвертка	n/a	2	Баран	20	8	Черепаха	n/a	1	Мочалка	n/a	3
2	Плащ	34	13	Вилка	n/a	7	Нож	72	n/a	Платье	74	71	Марка	19	28	Бритва	n/a	7
3	Гайка	23	7	Пистолет	22	28	Бархат	n/a	15	Галстук	18	21	Рыбка	n/a	16	Ложка	34	41
4	Карта	83	154	Открытка	25	18	Плащ	34	13	Картошка	68	28	Салфетка	n/a	16	Банка	47	62
5	Черепаха	n/a	1	Стул	65	98	Вилка	n/a	7	Череп	19	12	Спицы	n/a	2	Лампочка	23	30
6	Бусы	n/a	6	Книга	231	691	Гайка	23	7	Бубен	n/a	3	Заколка	n/a	n/a	Помада	n/a	7
7	Спицы	n/a	2	Копье	21	9	Флакончик	n/a	1	Спички	32	83	Тарелка	31	48	Зубная щетка	n/a	n/a
8	Шарик	31	24	Акула	n/a	4	Бусы	n/a	6	Шапка	62	77	Поезд	67	128	Карандаш	23	75
9	Марка	19	28	Фломастер	n/a	n/a	Зубная нить	n/a	n/a	Морковь	10	2	Карта	83	154	Брелок	n/a	n/a
10	Флакончик	n/a	1	Цветок	153	135	Шарик	31	24	Фломастер	n/a	n/a	Ручка	15	50	Салфетка	n/a	19
	Mean	38	25		86	122		40	9		38	34		43	49		32	31
	SD	26	46		87	234		22	8		26	34		30	55		11	27