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Sensitivity to Phonological Similarity Within and Across Languages

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Abstract

The influence of phonological similarity on bilingual language processing was examined within and across languages in three experiments. Phonological similarity was manipulated within a language by varying neighborhood density, and across languages by varying extent of cross-linguistic overlap between native and non-native languages. In Experiment 1, speed and accuracy of bilinguals' picture naming were susceptible to phonological neighborhood density in both the first and the second language. In Experiment 2, eye-movement patterns indicated that the time-course of language activation varied across phonological neighborhood densities and across native/non-native language status. In Experiment 3, speed and accuracy of bilingual performance in an auditory lexical decision task were influenced by degree of cross-linguistic phonological overlap. Together, the three experiments confirm that bilinguals are sensitive to phonological similarity within and across languages and suggest that this sensitivity is asymmetrical across native and non-native languages and varies along the timecourse of word processing.

Keywords

Phonology; Language production; Language recognition; Bilingualism; Eye-tracking

Introduction

The human linguistic capacity is subject to multiple influences both from within and outside the language system. One of the factors found to have a particularly robust influence on language processing is how similar or different a word is to other words, for example, in terms of sound structure. Empirical evidence from studies with monolinguals suggests that a word's phonological similarity to other words influences its recognition in the visual modality (e.g., Dijkstra et al. 1999; Ferrand and Grainger 1994; Perfetti and Bell 1991; Van Orden 1987; Van Orden et al. 1988; Yates et al. 2004), in the auditory modality (e.g., Garlock et al. 2001; Luce and Pisoni 1998; Metsala 1997; Slowiaczek et al. 2003; Vitevitch and Luce 1998; Ziegler et al. 2003), and during production (e.g., Costa and Sebastian-Galles 1998; Harley 1984; Harley and Bown 1998; Vitevitch and Sommers 2003; James and Burke 2000; Meyer and Bock 1992; Vitevitch 1997, 2002).

The majority of early studies on the role of phonology in bilingual language processing focused on visual word recognition, and showed that both phonological and lexical access proceed in parallel across languages (e.g., Doctor and Klein 1992; Lam et al. 1991; Nas 1983). Increased

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phonological similarity has been found to either inhibit or facilitate bilingual language processing, depending on task demands. For example, studies of masked phonological priming revealed facilitative interlingual homophone priming from both the native to the non-native language, and from the non-native to the native language, and the magnitude of interlingual priming was similar to the magnitude of within-language priming (e.g., Brysbaert et al. 1999; Van Wijnendaele and Brysbaert 2002). In contrast, form primes in the non-native language inhibited target words in the native language (e.g., Silverberg and Samuel 2004); and native-language words inhibited lexical decision in the non-native language (e.g., Dijkstra et al. 1999; Nas 1983). These differences in results are likely due to variability in experimental tasks rather than in organization of the bilingual system. For example, it is possible that the masked priming tasks that yielded facilitation had activated sub-lexical phonological representations only, while lexical decision tasks that yielded cross-linguistic inhibition had activated both lexical and sub-lexical representations. Together, these studies suggest that phonological overlap may play variable roles at different stages of language processing (lexical or sub-lexical).

This latter hypothesis finds extensive support in monolingual studies of phonological processing at both lexical and pre-lexical stages (e.g., Harley and Bown 1998; Vitevitch and Luce 1998). At the lexical stage, phonological similarity has been shown to result in competition (and inhibition) between items during auditory word recognition (e.g., Slowiaczek et al. 2000). For example, during a shadowing task (where participants repeat words they hear), inhibition was found for targets that were preceded by high-overlap primes (e.g., *blast-black*), but not for non-words, suggesting that competition between similar-sounding words was localized to the lexical level (e.g., Slowiaczek and Hamburger 1992). Moreover, during auditory lexical decision, sparse-neighborhood words were identified faster than dense-neighborhood words (Luce and Pisoni 1998; Ziegler et al. 2003), a finding consistent with lexical-level competition mechanisms (such as those proposed in Luce and Pisoni's (1998) Neighborhood Activation Model, Marslen-Wilson's (1987) Cohort model, or McClelland and Elman's (1986) TRACE model), where competition from numerous words delays identification.

At the sub-lexical stage, phonological similarity has been shown to result in support (and facilitation) from shared representations during word recognition and production. For example, during an auditory lexical decision task, word primes were shown to facilitate target-word recognition when they shared rimes (e.g., beau-CORBEAU). Facilitation was found when both primes and targets were presented auditorily, but not when they were presented cross-modally, suggesting that facilitation was localized to the pre-lexical (modality-specific) level (e.g., Spinelli et al. 2001). In addition, production studies that elicited speech errors (Harley 1984) or induced tip-of-the-tongue states (e.g., Harley and Bown 1998; James and Burke 2000; Meyer and Bock 1992; Vitevitch and Sommers 2003) focused on retrieval of phonological form after successful lexical retrieval had taken place, and showed that dense phonological neighborhoods facilitated phonological access. This effect was also confirmed in naturally produced speech (e.g., Vitevitch 1997), and during picture-naming in normal (e.g., Vitevitch 2002) and aphasic (e.g., Gordon and Dell 2001; Gordon 2002) participants. It has been suggested that this neighborhood effect can be localized to facilitative feedback between lexical and sub-lexical phonological levels. Similarly, when sub-lexical phonological structures (such as word-initial phonemes or syllables) were targeted during priming in picture-word interference and reading tasks (e.g., Costa and Sebastian-Galles 1998), results revealed that phonological overlap facilitated phonological access. In sum, while competition effects during auditory word recognition have been localized to the lexical level, facilitation effects during recognition and production have been localized to a pre-lexical phonological level.

In bilinguals, these differences across stages of processing may be further influenced by target language (native or non-native) and language proficiency (high or low; for a discussion of the effects of methodological variability on study results, see Grosjean 1997; Marian 2007). With respect to language status, studies of auditory language comprehension have shown that the effect of cross-linguistic overlap on language processing is observed more readily in the non-native language than in the native language (e.g., Weber and Cutler 2004). Studies of language production have also demonstrated an asymmetry between native and non-native language processing, with the native language influencing production in the non-native language, but not vice versa (e.g., Jared and Kroll 2001). Recently, support for an asymmetry in native/non-native phonological processing has come from eye-tracking experiments. While numerous studies found native language activation during non-native language processing (Blumenfeld and Marian 2005; Marian and Spivey 2003a,b; Weber and Cutler 2004; Weber and Paris 2004; but see Spivey and Marian 1999), findings of non-native language activation during native language processing have been mixed (Ju and Luce 2004; Marian and Spivey 2003b; Weber and Cutler 2004). The exact mechanism of the asymmetry in native and non-native language processing remains unknown; however, language proficiency may be an important mediator. Previous research confirms that highly proficient late bilinguals exhibit form-priming from the non-native language into the native language, while less proficient late bilinguals do not (Silverberg and Samuel 2004). Similarly, Van Hell and Dijkstra (2002) found that Dutch–English–French trilinguals responded faster in a native-language lexical decision task when stimuli shared form and meaning (i.e., were cognates) with a word in their more proficient non-native language, but not when the stimuli were cognates with a word in their less proficient non-native language. Together, these results suggest that as the level of proficiency changes, so does the pattern of native and non-native language interaction (the dynamic nature of the bilingual lexicon, as influenced by language proficiency, is reflected in the Revised Hierarchical Model of bilingual language processing, Kroll and Stewart 1994).

The Current Study

To examine the roles of phonological similarity and language proficiency at lexical and sub-lexical stages, the present research used a multifaceted approach to study native and non-native language processing in bilinguals. The influence of phonological similarity was investigated both *within* and *across* languages in three experiments. In Experiment 1, *within-language* phonological overlap was manipulated by varying the target word's phonological neighborhood density in a single language. Bilinguals named words with high- and low-density phonological neighborhoods in either their native or non-native language. In Experiment 2, phonological overlap was manipulated both *within* and *across* languages. Within-language phonological overlap was manipulated by varying phonological neighborhood density in a single language. Cross-linguistic phonological overlap was manipulated by varying phonological similarity between the target word and a cross-linguistic competitor word. Bilinguals performed an auditory word identification task and the time-course of co-activation was examined using eye-movements to dense-neighborhood and sparse-neighborhood cross-linguistic competitor words. In Experiment 3, the degree of *cross-linguistic* phonological overlap was manipulated at the sub-lexical level by constructing stimuli with phonemes that were either unique to one language or shared across languages. Bilinguals performed an auditory lexical decision task for words with 0-phoneme overlap, 1-phoneme overlap, 2-phoneme overlap or complete overlap with the non-target language.

It was expected that each task would target different stages of processing, and that these differences would be reflected in latency measures across experiments. Eye-movements in Experiment 2 (where participants received acoustic input and recognized a corresponding picture) would reflect early phonological co-activation and subsequent lexical competition. Response latencies in Experiment 3 (where participants received acoustic input and made a decision about its lexical status) would reflect later co-activation and interference at the decision stage. Response latencies during picture naming (Experiment 1) would reflect late co-activation of overlapping phonological representations, and facilitation at the output stage. Together, the three experiments were designed to complement each other and provide a comprehensive picture of the role of phonology in bilingual lexical access. The different tasks targeted different stages of language processing and examined how the time-course of lexical activation may be influenced by proficiency and by phonological overlap within and across languages. It was predicted that increased phonological similarity within- and across languages would influence bilinguals' performance and that the effects of phonological similarity would vary across native and non-native languages.

Experiment 1: Effect of Within-language Phonological Overlap on Lexical Access in Bilinguals

The objective of Experiment 1 was to examine the role of within-language phonological overlap during native and non-native picture naming. The degree of within-language phonological overlap was manipulated by varying phonological neighborhood density of the target word. A word's neighborhood size (a.k.a., neighborhood density) was defined as the number of other words that differed from the target word by a single phoneme (e.g., Grainger et al. 2005; Yates et al. 2004). Previous studies with monolinguals showed that phonological neighborhood density influences word production. Targets with dense phonological neighborhoods were retrieved more rapidly than targets with sparse phonological neighborhoods in picture naming tasks and in tasks that induced tip-of-the-tongue states (e.g., Vitevitch 2002; Vitevitch and Sommers 2003; Harley and Bown 1998).

In Experiment 1, the influence of phonological neighborhood density on lexical access in bilingual language production was investigated in German–English (German-native) and English–German (English-native) bilinguals. Participants were asked to produce targets with either high-density or low-density phonological neighborhoods in German. The language of testing was kept constant throughout the experiment, in order to avoid any cross-linguistic differences in language structures. Instead, native/non-native status was manipulated by testing two groups of bilinguals—one for whom the target language was the native language, and one for whom the target language was the non-native language.

It was predicted that the pattern of results in the native language would replicate that of previous studies with monolinguals. Higher accuracy and shorter latency rates were predicted for words with dense phonological neighborhoods than for words with sparse phonological neighborhoods. In addition, the paradigm was extended to production in a non-native language. Lower proficiency levels in the non-native language were predicted to influence results. Two alternative hypotheses were considered. On the one hand, if sensitivity to phonological neighborhood density emerged with language proficiency, then neighborhood effects would be more apparent in native naming than in non-native naming. On the other hand, if lower proficiency levels rendered 'low frequency status' to all words in that language, then sensitivity to phonological neighborhood density would be more apparent in non-native naming than in native naming (based on previous findings of stronger neighborhood effects during production of low-frequency words, e.g., Vitevitch, 1997). In sum, participants were predicted to be faster and more accurate for large-neighborhood words than for small-neighborhood words, with the magnitude of the effect differing across native and non-native languages.

Methods

Participants—Twenty-nine bilingual speakers of German and English were tested. Of these, 14 were native speakers of English (6 females), and 15 were native speakers of German (7 females). The mean age at the time of testing was 25.6 years (*SD* = 8.9) for the English–German bilinguals and 28.7 years (*SD* = 12.9) for the German–English bilinguals, with no significant difference between the two, *t* (27) = 0.8, *p* > .1. German–English bilinguals started learning English at the average age of 10.7 years (*SD* = 3.3). English–German bilinguals started learning German at the average age of 11.5 years (*SD* = 8.4). At the time of study, bilinguals reported having more exposure to English than to German, *t* (27) = 2.6, *p* < .05. All participants were administered the English Peabody Picture Vocabulary Test (PPVT-III, Dunn and Dunn 1997), and English-native bilinguals (*M* = 195.3,[1] *SD* = 3.7) outperformed German-native bilinguals (*M* = 172.7, *SD* = 15.2), *F* (2, 42) = 22.3, *p* < .001. Participants were also administered a German translation of the PPVT, and German–English bilinguals (*M* = 193.9, *SD* = 7.6) outperformed English–German bilinguals (*M* = 178.6, *SD* = 18.2), *t* (27) = 2.9, *p* < .01. German was the preferred language for 11 German–English bilinguals, and 4 German–English bilinguals had no preference; English was the preferred language for 7 English–German bilinguals, and 7 English–German bilinguals had no preference.

In this and all subsequent experiments, participants filled out a questionnaire about their language background upon completion of the experimental session. None of the participants had language, learning, or hearing disabilities. Participants were treated in accordance with the ethical standards of the APA and were paid for participation.

Materials—Fifty-seven pictures corresponding to German target words were used. Picture stimuli were black line drawings with gray shadings (see Fig. 1) and were selected from the IMSI Master Clips electronic database and the Alta Vista search engine, or hand-drawn. To identify phonological neighbors of each target word, the German corpus of the CELEX lexical database (Baayen et al. 1995) was used, with an item coded as a phonological neighbor if it differed from the target by only one phoneme, and had the phonemes in the same positions (Grainger et al. 2005;Yates et al. 2004). For example, the phonological neighborhood of the German word *Hase* / haz / included such words as *Vase* / vaz / (*vase*), *Hose* / hoz / (*pants*), and *habe* / hab / (*have*).[2]

Stimuli were grouped into two conditions, one condition included words with large phonological neighborhoods (3 or more phonological neighbors in German) and the other condition included words with small phonological neighborhoods (2 or fewer phonological neighbors in German). An example of a stimulus word with a large phonological neighborhood is the German word for *roof*, *Dach* / dax/, whose German phonological neighborhood includes *doch* / d x/ (*still*), *dann* / dan/ (*then*), *das* / das/ (*the*), *Damm* / dam/ (*dam*), *Fach* / fax/ (*drawer*), *wach* / vax/ (*awake*), *mach* / max/ (*make*), and *Bach* / bax/ (*creek*). An example of a stimulus word with a small phonological neighborhood is the German word for *record*, *Platte* / plat /, whose German phonological neighborhood consists of *Pleite* / pla t / (*bankrupt*) and *platt* / plat/ (*flat*). The large-neighborhood condition consisted of 31 German words, with a mean neighborhood size of 5.8 words (*SE* = 0.4). The small-neighborhood condition consisted of 26 German words, with a mean neighborhood size of 1.2 words (*SE* = 0.2). The neighborhood sizes for the two conditions were significantly different from each other *t* (55) = 8.8, *p* < .001. (The rationale for choosing a significant, but relatively small, difference between dense and sparse neighborhood conditions was to specifically address the question of *sensitivity* to small changes in neighborhood density across native and non-native

[1]For the English PPVT, raw scores were provided instead of standard scores, so that comparisons between performance on the English PPVT and the German unstandardized PPVT would be possible.

[2]Note that the ideal scenario would be to also manipulate the phonological neighborhood density of English, in order to gauge the separate effect of non-target language phonological neighborhood, as well as the cumulative effect of phonological neighborhoods across both languages. However, that was not possible because differences in phonetic features between German and English precluded meaningful computations of corresponding phonological neighborhoods for English.

languages.) Words in the two conditions were balanced for word length (in phonemes), spoken word frequencies of German and of English translation equivalents (CELEX lexical database, Baayen et al. 1995), orthographic neighborhood size in German and English, and number of synonyms available in German. There were no significant differences for these measures between the low-density neighborhood and the high-density neighborhood conditions ($p > .05$). Complete lists of all stimuli used in this and subsequent experiments, along with detailed information on stimulus characteristics and control dimensions, are available by request (Table 1).

Design and Procedure—The experiment followed a 2×2 design, with Neighborhood Size (high-density, low-density) as a within-group variable and Language Status (native German speakers, non-native German speakers) as a between-group variable. The dependent variables were latency and accuracy of response. Participants were tested by a German–English bilingual. For the experimental task, participants were seated in front of a computer screen and were asked to name pictures that appeared on the screen. Responses were recorded using a Logitech microphone. The experiment was self-paced, and there was a 500 ms inter-trial-interval. Pictures were presented in a random sequence (generated by Super Lab experimental software) to avoid order effects across items and conditions (such as trial-to-trial priming).

Coding and Analyses—For reaction time, time from onset of picture presentation to onset of word production was measured in milliseconds. Reaction time was derived from the experimental software's output. For accuracy, the percentage of pictures named correctly using the target word was computed. An answer was coded as incorrect when it was not an acceptable label of the picture. Of the 1,653 responses produced, 62.5% (1,033 cases) were coded as correct and 37.5% (620 cases) were coded as errors. All data were coded by a fluent German speaker. Another fluent German speaker coded 20% of the data; point-to-point reliability between the two coders was 94% (pair-wise Pearson's *R*).

Reaction time and accuracy patterns were analyzed using two-way Analyses of Covariance, with Phonological Neighborhood Size (large, small) and Group (native German speakers, non-native German speakers) as independent variables, and with participants' number of years of education as a covariate. Participants' number of years of education was entered as a covariate, in order to factor out the confounding influence of academic experience, which is known to correlate highly with IQ scores, processing speed, and familiarity with de-contextualized tasks (see Brody 1992; Ceci 1996; Neisser et al. 1996).

Results

Reaction time analyses revealed a main effect of neighborhood size, with faster naming of words with high-density neighborhoods (M = 2, 474.7 ms, SE = 262.5 ms) than of words with low-density neighborhoods (M = 2, 707.4 ms, SE = 261.5 ms), $F(1, 27) = 8.4$, $p < .01$. Moreover, a main effect of group revealed that native speakers named pictures faster (M = 2, 066.8 ms, SE = 266.5 ms) than non-native speakers (M = 3, 115.3 ms, SE = 257.5 ms), $F(1, 27) = 9.2$, $p < .01$. The interaction between neighborhood size and group did not reach significance, $p > .05$. Planned follow-up t-tests revealed that non-native speakers were faster naming pictures of words with high-density neighborhoods (M = 2, 954.0 ms, SE = 222.0 ms) than pictures of words with low-density neighborhoods (M = 3, 277.0 ms, SE = 222.0 ms), $t(13) = 2.9$, $p < .05$; for native speakers, the difference was not significant, $p > .050$. (The relatively long naming latencies may be due in part to the fact that participants were not instructed to name pictures as rapidly as possible. In general, picture-naming takes longer in bilinguals than in monolinguals, e.g., Costa et al. 2000).

Accuracy analyses revealed a main effect of neighborhood size, F (1, 27) = 9.2, $p < .01$, and a main effect of group, F (1, 27) = 42.2, $p < .001$. Naming accuracy was higher for target words with large phonological neighborhoods (*M* = 67.9%, *SE* = 2.4%) than for target words with small phonological neighborhoods (*M* = 59.9%, *SE* = 2.4%) and was also higher for native speakers (*M* = 79.0%, *SE* = 3.2%) than for non-native speakers (*M* = 48.8%, *SE* = 3.3%). Phonological neighborhood size influenced naming accuracy similarly across both groups, with no interaction between neighborhood size and group, F (1, 27) = 3.5, $p > .05$.

Discussion

Findings of Experiment 1 suggest that within-language phonological overlap influences naming in bilinguals. The present experiment replicated previous findings of neighborhood density effects in native speakers and extended the study of phonological neighborhood density to production in a non-native language. Similar to accuracy patterns in native-language naming, accuracy in non-native language naming was also facilitated by high-density phonological neighborhoods. However, latency results varied across native and non-native languages. High-density neighborhoods appeared to facilitate naming latency more in the non-native language than in the native language. This suggests that retrieval difficulties in sparse neighborhoods may be more marked for non-native speakers, supporting the prediction that language proficiency influences sensitivity to within-language phonological overlap. Differences in response times between languages could be due to lower proficiency in the non-native language rendering overall 'low frequency status' to all words in that language. This, in turn, may have made non-native language naming more sensitive to phonological neighborhood density. Consistent with previous explanations of neighborhood density effects during production (Dell 1986; Gordon and Dell 2001), the increased sensitivity in non-native speakers can be localized to the sub-lexical level, or to mappings between the sub-lexical and lexical levels. In addition, it is possible that, at the sub-lexical level, organization of phonetic representations into phonemic categories differs between native and non-native languages, with less well-defined categories in the non-native language. Such differences might influence the number of phonological neighbors activated during word retrieval and result in native/non-native differences.

Another reason for diminished latency differences between high- and low-density neighborhoods in a native language may be the relatively small contrast between high- and low-density conditions employed in the present study. While this difference was statistically significant, it is noticeably smaller than differences between sparse and dense neighborhoods in other neighborhood-density studies (e.g., Garlock et al. 2001; Vitevitch 2002; Yates et al. 2004). The fact that accuracy results showed a phonological neighborhood effect in the current dataset speaks to the robustness of the phenomenon. The fact that latency results did not show a phonological neighborhood effect in a native language suggests that *speed* of access is less sensitive to small variations in neighborhood density than *accuracy* of access. It is possible then, that accuracy is more sensitive to even slight variations in neighborhood density, while latency differences are triggered by more dramatic changes, at least in a highly proficient language. In sum, results of Experiment 1 suggest that phonological similarity between words influences word retrieval during both native and non-native naming, and that efficiency of retrieval is particularly sensitive to phonological similarity in non-native contexts. To further examine whether the influence of phonological overlap on lexical access is restricted to the target language of processing, or whether similar activation dynamics can also be found *across* languages, a second experiment was designed.

Experiment 2: Effect of Within- and Across-language Phonological Overlap on Lexical Access in Bilinguals

The objective of Experiment 2 was to measure the influence of within- and between-language phonological overlap on lexical retrieval. To investigate activation dynamics of dense and sparse neighborhood words in more detail, a word recognition task was chosen that allowed for covert indexing of lexical activation using eye-movements. Within-language phonological overlap was varied by manipulating the size of the cross-linguistic competitor's phonological neighborhood, and between-language phonological overlap was varied by manipulating similarity between the target onset and the cross-linguistic competitor onset. An additional contribution of Experiment 2 consists of introducing eye-tracking as a tool to study neighborhood effects. Eye-tracking provides a non-linguistic measure of language activation (e.g., Tanenhaus et al. 1995, 2000) and can supply additional information about the time-course of bilingual language processing (e.g., Marian and Spivey 2003a,b; Spivey and Marian 1999).

Previous results from eye-tracking suggest that phonological overlap between words influences the time-course of lexical activation in monolinguals (e.g., Allopenna et al. 1998; Dahan and Tanenhaus 2005). For example, in a within-language eye-tracking study, Allopenna et al. (1998) found parallel activation of target and competitor words both when their onsets overlapped (e.g., *beaker-beetle*), and when their rimes overlapped (e.g., *beaker, speaker*). This finding suggests that phonological overlap anywhere within a word results in lexical co-activation and predicts that, during selection of a target word, other words in its neighborhood become active. Evidence from other within-language recognition studies suggests that large neighborhood size yields increased competition and delayed selection of the target word. In contrast, small neighborhood size yields reduced competition and speeds up recognition of the target word (e.g., Bradlow and Pisoni 1999; Garlock et al. 2001; Luce and Pisoni 1998; Vitevitch and Luce 1998; Ziegler et al. 2003). Therefore, during auditory word recognition, low-density words are activated more readily than high-density words. In the bilingual literature, the few studies that examined the role of phonological neighborhood density in auditory language processing showed that the magnitude of the neighborhood density effect differed across native and non-native languages. For example, Bradlow and Pisoni (1999) found that both native and non-native listeners identified ‘easy’ words with sparse neighborhoods more accurately than ‘hard’ words with dense neighborhoods. However, the difference between easy and hard words was larger for non-native listeners than for native listeners (also see Takayanagi et al. 2002), suggesting that bilinguals may be particularly likely to activate low-density words in a non-native language.

In Experiment 2, the influence of phonological similarity within and across languages was examined during bilingual word recognition in German–English and English–German bilinguals, as well as in a control group of English monolinguals. Between-language overlap was manipulated across target and competitor words. Participants listened to and identified English target words (such as *desk*), from a set of four pictures that included a picture of a similar-sounding German competitor (such as *Deckel*/lid). Within-language overlap was manipulated by varying the neighborhood density of German competitors (competitors had either high-density or low-density phonological neighborhoods in German). The language of testing was kept constant throughout the experiment; participants were tested in English, and co-activation of German competitors was measured via eye-movements. Co-activation of German competitors captured both the influence of between-language overlap (measured by looks to between-language competitors vs. looks to neutral control objects), as well as the influence of within-language overlap (measured by looks to high-density competitors vs. looks to low-density competitors, relative to controls). It was expected that the activation pattern of the native language would replicate previous studies on recognition of high-and low-density

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words in monolinguals. Since sparse-neighborhood words are recognized faster than dense-neighborhood words, stronger co-activation of German was predicted for German competitors with sparse phonological neighborhoods than for German competitors with dense phonological neighborhoods. For the non-native language, lower proficiency levels were predicted to influence the pattern of parallel language activation. Consistent with results of Experiment 1, it was expected that the non-native language would be more sensitive to phonological neighborhood density than the native language. In sum, it was predicted that, during English word processing, bilinguals would activate German competitors with sparse phonological neighborhoods more than German competitors with dense phonological neighborhoods. It was also predicted that the magnitude of the effect would differ across native and non-native languages.

Methods

Participants—Participants in Experiment 2 included the same bilinguals as in Experiment 1. In addition, a group of English monolinguals ($N = 15$, Age = 27.3, $SD = 9.3$; 9 females) was tested. Monolinguals were included in order to ensure that any differences observed between activations of competitor and control items reflected co-activation of the two languages rather than artifacts of stimulus selection. On the English PPVT, English monolinguals ($M = 190.6$, $SD = 6.5$) performed similarly to English-native bilinguals ($M = 195.3$, $SD = 3.7$), $p > .1$, and outperformed German-native bilinguals ($M = 172.7$, $SD = 15.2$), $F\ (2, 42) = 22.3$, $p < .001$.

Stimuli—Stimulus displays consisted of panels with four pictures and a central fixation cross. In half (57) of all trials, target-pictures were accompanied by pictures of German competitors that had word-onsets similar to the word-onsets of targets [e.g., the German competitor *Deckel* (*lid*) competed with the English target *desk*]. The overlap between targets and competitors was coded according to the International Phonetic Alphabet (IPA 1999). In the other half of all trials, target-pictures were accompanied by control items that were not phonologically similar to the target [e.g., the German control item *Kaefer* (*bugs*) accompanied the English target *desk*]. The German competitors in Experiment 2 corresponded to the target words in Experiment 1, and varied similarly in neighborhood density. For example, the large-neighborhood word *Dach/roof* competed with the English target *dove*. The small-neighborhood word *Platte*/record competed with the English target *plug*. In addition to competitor pictures, English target pictures were constructed. Positioning of pictures in quadrants I–IV of the visual display was controlled across trials, and the order of trials was counterbalanced across participants and conditions. Stimulus sets were balanced for spoken word frequency in both English and German using the CELEX lexical database [Baayen et al. 1995; $F\ (9, 310) = 0.4$, $p = .9$]. For samples of visual displays used in Experiment 2, see Fig. 2.

The auditory instructions "*click on the* [*target picture*] *and the* [*filler picture*]" were presented concurrently with picture displays. Recordings of auditory stimuli were made by a female speaker of American English in a sound-proof booth. The resulting sound files were normalized to a uniform amplitude using DigiSound software, and were exported into Super-lab. Further segmentation and insertion of equal between-word breaks was performed using Sound Studio software. The name of the target-picture was presented 400 ms after presentation of the picture display. The experiment was self-paced, but the onset of words for the filler picture was always presented 3,000 ms after presentation of the picture display. Instructions to click on a filler picture were included to disguise the purposes of the experiment, and to prevent participants from noticing overlap patterns. In the post-experiment interview, none of the participants identified the purpose of the study. In 3.6% of all trials, participants noticed overlap between targets and competitors; these trials were excluded from further consideration and were not coded.

Design and Procedure—The present study followed a 2 × 2 × 2 × 3 design, with Competitor (cross-language competitor, neutral control), the competitor's Neighborhood Size (high-density, low-density), and Time-course of Co-activation (early, late) as within-group variables, and Group (German-native, English-native, monolingual) as a between-group variable.

Participants were tested by a fluent speaker of English. German was not used at any point during the experiment. Participants were fitted with a head-mounted ISCAN eye-tracker. A scene camera provided an image of the participants' field of view. A second camera, which provided an infrared image of the left eye, allowed the software to track the center of the pupil and the corneal reflection. Gaze position was indicated by cross-hairs superimposed over the image generated by the scene camera. Participants' eye-movements were calibrated to 9 points on the computer screen (G4 Macintosh, 27 cm × 34 cm). Participants were familiarized with the task during a five-trial practice run on neutral stimuli that did not re-occur during the experimental session.

Coding and Analyses—Eye-tracking data consisted of video output including participants' superimposed field of view and fixation cross-hairs, as well as auditory instructions, which were time-locked to participants' eye-movements. The video output was manually coded at a temporal resolution of 33.3 ms per frame using Final Cut software. Eye-movements to pictures were coded as looks if they entered the picture's quadrant and remained there for at least one frame. Fifteen percent of all data were re-coded by a second coder; point-to-point inter-rater reliability was 93.5% (pair-wise Pearson R). A total of 7.8% of data were excluded from analyses due to problematic competitor stimuli, which drew consistently more looks to competitor than to control items in the monolingual group.

Data were analyzed by coding the time-course of eye-movements to targets, competitors, and control items frame by frame for both the high-neighborhood and the low-neighborhood conditions and across all participant groups. Average percentages of looks across time windows and activation curves of competitor vs. control items were compared across conditions and participants.

Results

An overall 2× 2× 2× 3 ANOVA (Competitor × Neighborhood × Time × Group) on proportion of eye-movements revealed significant main effects of neighborhood size [high = 8.7%, SE = 0.4%; low = 7.5%, SE = 0.3%; F (1, 42) = 9.2, $p < .005$], time frame [early = 13.1%, SE = 0.6%; late = 3.1%, SE = 0.2%; F (1, 42) = 233.9, $p < .001$], and competitor [competitor = 8.5%, SE = 0.3%; control = 7.7%, SE = 0.3%; F (1, 42) = 10.0, $p < .005$], and significant interactions between competitor and group [F (2, 42) = 10.0, $p < .005$] and between neighborhood density and group [F (2, 42) = 3.5, $p < .05$].

Follow-up analyses examined the time-course of activation for low- and high-neighborhood German competitors, relative to control items (see Fig. 3). For German competitors with *low-density neighborhoods*, differences in activation time-course were found across groups. While German-native bilinguals co-activated low-density neighborhood competitors during a later time-window (900–1,500 ms), English-native bilinguals co-activated low-density neighborhood competitors during an earlier time-window (300–500 ms). Monolingual participants did not co-activate low-density neighborhood competitors. A 2 × 2 × 3 ANOVA (Competitor × Time × Group) for these time-frames yielded a significant interaction between Competitor, Group, and Time, F (2, 42) = 5.7, $p < .05$, suggesting that these differences in parallel language activation across groups and time-frames were significant. Follow-up 2× 3 ANOVAs (Competitor × Group) were conducted for both the 300–500 ms time-frame and for the 900–1,500 ms time-frame. During the 300–500 ms time-frame, a significant interaction between Competitor and Group was found, F (2, 42) = 4.4, $p < .05$, with English-native bilinguals looking at German low-density competitors (*M* = 12.4%, *SE* = 1.2%) more than at control items (*M* = 8.2%, *SE* = 0.9%), *t* (14) = 2.7, *p* < .01, German-native bilinguals looking equally often at competitor (*M* = 12.3%, *SE* = 1.7%) and control items (*M* = 12.4, 1.1%), *t (*14*)* = −.08, *p* < .1, and English monolinguals looking equally often at competitor (*M* = 10.1, *SE* = 1.4%) and control items (*M* = 10.1, *SE* = 1.2%), *t* (14) = 0.001, *p* > .1. During the 900–1,500 ms time-window, a significant interaction between Competitor and Group was also found, *F* (2, 42) = 7.3, *p* < .01, with German-native bilinguals looking more at low-neighborhood competitors (*M* = 7.7%, *SE* = 0.8%) than at control items (*M* = 4.5%, *SE* = 0.7%), *t* (14) = 3.7, *p* = .001, English-native bilinguals looking equally often at low-neighborhood competitors (*M* = 1.8%, *SE* = 0.03%) and at control items (*M* = 1.3%, *SE* = 0.02%), *t* (14) = 1.1, *p* > .1, and English monolinguals looking equally often at low-neighborhood competitors (*M* = 2.6%, *SE* = 0.6%) and at control items (*M* = 2.7%, *SE* = 0.7%), *t (*14*)* = −0.2, *p* > .1.

For German competitors with *high-density neighborhoods*, German-native bilinguals showed parallel activation while English-native bilinguals and monolinguals did not. German-native bilinguals co-activated German high-density competitors during the 200–500 ms time window, and a significant interaction between Competitor and Group was found during this time-window, *F* (1, 28) = 4.5, *p* < .05. Follow-up *t*-tests during the 200–500 ms time-window revealed that German-native bilinguals looked more at high-neighborhood competitors (*M* = 15.7%, *SE* = 1.5%) than at control items (*M* = 12.9%, *SE* = 1.3%), *t* (14) = 1.7, *p* = .05, while English-native bilinguals looked equally often at competitor (*M* = 13.4%, *SE* = 1.2%) and control items (*M* = 12.3%. *SE* = 1.1%), *t* (14) = 1.4, *p*> .05, and English monolinguals looked equally often at high-neighborhood competitors (*M* = 14.4%, *SE* = 1.3%) and at control items (*M* = 16.2%, *SE* = 1.4%), *t (*14*)* = −1.3, *p* > .1.

Discussion

Findings of Experiment 2 suggest that both between- and within-language phonological overlap influences auditory word recognition in bilinguals. Phonological overlap *between* languages (i.e., between English targets and German competitors) resulted in parallel language activation. For native German-speakers, German was consistently activated when either high- or low-density competitors were present; however, for non-native German speakers, German was only activated when low-density competitors were present. In addition, competitors with low-density neighborhoods were co-activated for a longer duration of time in the native language than in the non-native language. Stronger activation of the native language may be due to its higher baseline activation level. It is likely that lower overall activation levels (and higher activation thresholds) decrease the probability of non-native language co-activation during native-language processing. Together, findings suggest that the influence of cross-linguistic phonological overlap is strongest when bilinguals are processing words in their non-native language.

Further, high phonological overlap *within* a language (i.e., German competitors with dense neighborhoods) resulted in reduced parallel activation of both native and non-native languages. In the native language, high-density competitors were co-activated for a shorter period of time (300 ms) than low-density competitors (600 ms). In the non-native language, high-density competitors were not co-activated, while low-density competitors were briefly co-activated (200 ms). For both native and non-native languages, differences in activation of high and low-density competitors may be explained by a common mechanism. It is more difficult to recognize high-density words than low-density words (e.g., Luce and Pisoni 1998; Vitevitch and Luce 1998), likely due to simultaneous activation of multiple similar-sounding neighbors. Consistent with the Neighborhood Activation Model (Luce and Pisoni 1998), increased competition from multiple phonological neighbors may result in low activation of high-density words (also see Slowiaczek et al. 2000). Therefore, during bilingual processing, cross-linguistic competitors with high-density neighborhoods may be less likely to become co-activated than cross-linguistic competitors with low-density neighborhoods. Furthermore, studies of auditory word recognition have suggested that non-native speakers experience particular difficulty recognizing words with high-density neighborhoods (Bradlow and Pisoni 1999; Takayanagi et al. 2002). This difficulty may explain absence of high-density competitor activation in the non-native group. Overall, high phonological overlap within-language appears to reduce the extent of co-activation of native and non-native cross-linguistic competitors. Moreover, findings suggest that low-density words are co-activated regardless of language status, likely due to decreased competition from neighboring words.

Furthermore, the time-course of parallel activation varied across neighborhood size and native/non-native language status. Native German speakers activated German high-density competitors during an earlier time-frame (200–500 ms post-stimulus onset), and activated German low-density competitors during a later time-frame (900–1,500 ms pso). In contrast, non-native German speakers did not activate German high-density competitors, and activated German low-density competitors during an earlier and shorter time-frame (300–500 ms pso). This asymmetric pattern across native and non-native languages may be explained in terms of a mechanism specific to the native language. As native speakers face consistent co-activation of their native language during non-native language processing, a native language control mechanism may develop over time in order to avoid native-language interference. Specifically, such a mechanism may suppress co-activation of the native language beyond a certain threshold. Further, the control mechanism may act during early stages of lexical processing, when activation of the target is most vulnerable to interference from competitors. This mechanism may target native language co-activation in the presence of low-density competitors (which are readily activated) but not in the presence of high-density competitors (which are activated less readily, and may not surpass the activation threshold triggering the control mechanism). Such an account would explain native/non-native differences and later co-activation of low-density competitors in the native language. In German-native bilinguals, German low-density competitors were co-activated during a later time-window, when English targets were already highly active. Therefore, interference with target selection was highly unlikely at that time. It may be the case that activation of the German competitor was suppressed early on, until a late stage of target activation had been reached. Moreover, since activation of high-density competitors was found at *early* stages of native language processing, it is likely that this suppression mechanism comes into effect only when co-activation of the native language is strong. Thus, two explanations may account for the observed patterns of parallel activation across neighborhood density and language status. First, differences in baselines of language activation may influence whether (and for how long) parallel activation occurs.[3] Second, a suppression mechanism associated with the native language may determine onset of co-activation when competitor activation is particularly strong (and exceeds a certain threshold). Further research is needed to test these two explanations and to confirm the existence of a control mechanism that regulates the extent of native language co-activation.

In sum, eye-movements to pictures of German competitors during English word recognition were found to reflect not only co-activation of German competitors, but also co-activation of the competitors' neighborhoods. This suggests that during word recognition in one language, bilinguals co-activate a wide network of similar-sounding words in their other language. Further, the size of the network may determine extent of parallel language activation. Therefore, during bilingual language processing, phonological overlap within and between

[3]In addition, it should be noted that the extent of parallel German activation may be influenced by the targets' neighborhood size in English. In the low-neighborhood condition, English neighborhoods of English targets (*M* = 9.2, *SE* = 1.9) were larger than German neighborhoods of German competitors (*M* = 1.2, *SE* = 0.2). Similarly, in the high-neighborhood condition, English neighborhoods of English targets (*M* = 9.8, *SE* = 1.5) were also larger than German neighborhoods of German competitors (*M* = 5.8, *SE* = 0.4).

languages may interact to shape phonological similarity effects. It remains to be seen just how exactly this network of similar-sounding words in the other language is influenced by extent of phonological overlap *across* languages. A separate experiment was designed to investigate how *degree* of overlap between languages influences native and non-native auditory word recognition.

Experiment 3: Effect of Cross-linguistic Phonological Overlap on Lexical Access in Bilinguals

The objective of Experiment 3 was to examine the role of cross-linguistic phonological overlap during native and non-native language processing in the auditory domain. Bilingual participants were asked to perform an auditory lexical decision task in both native and non-native languages. In this experiment, Russian–English bilinguals were tested. Speakers of Russian were selected because Russian and English share fewer phonemes than German and English (the languages used in Experiments 1 and 2). The more marked differences between Russian and English (compared to German and English) allowed us to construct stimuli with varying degrees of cross-linguistic phonemic overlap.

Experiment 3 was modeled after a study by Jared and Kroll (2001), who examined the activation of phonological representations in bilinguals' two languages in native and non-native-language production. English–French and French–English bilinguals read aloud words with varying consistency of grapheme-to-phoneme mappings across languages. The stimuli were presented in three phases: an English-words phase, a French-filler phase, and another English-words phase. French-native bilinguals activated French spelling-to-sound correspondences while reading in English, as indicated by increased error rates and slower naming latencies for words with French competitors (words with different letter-to-sound mappings in French, e.g., *lait*). However, English-native bilinguals activated French spelling-to-sound correspondences only after completing a French filler phase, suggesting weaker interference from non-native French during native English production.

Similar to Jared and Kroll (2001), Experiment 3 tested the effect of cross-linguistic overlap on native and non-native language processing. The study design followed that of Jared and Kroll and included three language phases which made it possible to examine effects of phonological overlap on both native and non-native word recognition. The differences between the Jared and Kroll study and Experiment 3 were in (1) the modality of processing, and (2) ways in which input was varied. While Jared and Kroll targeted word production and manipulated orthographic overlap, the present experiment targeted auditory word recognition and manipulated phonological overlap. Most studies investigating the role of cross-linguistic phonological overlap typically use cognates, homophones, or homographs (e.g., Schulpen et al. 2003; Van Wijnendaele and Brysbaert 2002), which are usually the exception to bilingual linguistic input rather than the rule. In Experiment 3, non-homophonic, non-homographic stimuli were used, and their phonological consistency with the sound system of the native or the non-native language was manipulated by varying the number of phonemes unique to either one or the other language. Uniqueness was established after comparing corresponding phonemes in the native and the non-native language on their phonetic characteristics. Four levels of overlap (no-overlap, 1-phoneme overlap, 2 phoneme-overlap and 3-phoneme overlap) made it possible to manipulate phonological overlap in a gradual manner and perform a more fine-grained analysis of the impact of phonology on bilingual spoken word recognition.

It was predicted that cross-linguistic phonological overlap (and relevant sub-lexical representations of native and non-native languages) would activate both languages simultaneously and would influence latency and accuracy of bilingual word recognition. Moreover, the role of phonological overlap was predicted to vary across native and non-native languages. Specifically, overlap with a more proficient language was predicted to influence performance in a less proficient language to a greater extent than overlap with a less proficient language would influence performance in a more proficient language.

Methods

Participants—Twenty-six bilingual speakers of Russian and English (15 females) were tested. All bilinguals were native speakers of Russian. The mean age at the time of testing was 22.12 years (*SD* = 6.26). Bilinguals started learning English at the average age of 9.37 years (*SD* = 5.03). At the time of study, bilinguals reported having more exposure to English than to Russian, $t\,(25) = 3.68$, $p < .001$. English was the preferred language for 13 participants; Russian was the preferred language for 10 participants; 3 participants reported no language preference.

Materials—The stimuli were three-phoneme Russian and English words and non-word phoneme-sequences, coded according to the International Phonetic Alphabet (IPA 1999). All words were unique to Russian and English and no cognates, homophones, or homographs were used. Two-hundred-and-forty stimuli were divided into three sets: a Russian set, a first English set and a second English set. Each set consisted of 40 words and 40 non-words.

In each language set, the words were selected so that 10 were composed of phonemes unique to that language (0-phoneme overlap), 10 included two unique and one non-unique phonemes (1-phoneme overlap), 10 contained one unique and two non-unique phonemes (2-phoneme overlap), and the last 10 consisted of only phonemes non-unique to that language (3-phoneme overlap). Examples of 0-phoneme overlap words include the Russian word рыть /rɨtʲ/ (to dig) and the English word *wrong*; examples of 1-phoneme overlap words include the Russian word ночь /notʲʃʲ/ (night) and the English word *jam*; examples of 2-phoneme overlap words include the Russian word кит /kʲit/ (whale) and the English word *ink*; and examples of 3-phoneme overlap words include the Russian word шум /ʃum/ (noise) and the English word *peace*. The non-word stimuli were constructed in the same manner using unique and non-unique phonemes.

English vowels and consonants were compared to all corresponding Russian vowels and consonants to determine uniqueness. Pairs of corresponding phonemes were selected based on similarity in sound. For vowels, phonological characteristics used to evaluate uniqueness were tongue position in the vertical plane (low, mid, and high), lip articulation (rounded or not rounded), and tongue position in the horizontal plane (front, central, and back). For example, an English phoneme [a:] is a low, unrounded, back vowel and a Russian phoneme [a] is a low, unrounded, central vowel. Thus, [a:] and [a] share two phonological characteristics. Unique phonemes shared 0–2 characteristics; non-unique phonemes shared all three characteristics. English triphthongs (such as the vowel sequence in *flower*) were also considered unique, because Russian does not have a counterpart for triphthongs. For consonants, phonological characteristics used to evaluate uniqueness were voice participation (voiced or voiceless), palatalization (palatalized or not palatalized), place of articulation (bilabial, labio-dental, front-lingual dental, front-lingual dental-alveolar, palatal, palato-alveolar, back-lingual back-alveolar, velar and glottal) and manner of articulation (plosive, affricative, fricative, nasal, lateral, rolled and semi-vowel) (following Dickushina 1965). Consonants with fewer than two common features across languages were considered unique, and consonants that shared more than two features were considered non-unique.

Words were matched for frequency of occurrence within each language. Russian frequency was determined using Sharoff's online frequency dictionary (Sharoff 2003) based on a corpus of 16,000,000 words (http://bokrcorpora.narod.ru/frqlist/frqlist-en.html). English frequency was determined using the Kucera and Francis (1967) dictionary. All lists had similar mean frequencies. A one-way ANOVA (Phonological Overlap) on four subsets of Russian words revealed no differences in frequencies, F (3, 36) < 1. A 2 × 4 ANOVA (English Set × Phonological Overlap) for English word frequencies showed no main effect of English set [F (1, 68) < 1], no main effect of Phonological Overlap [F (3, 68) = 1.13, p = .34] and no interaction between the two [F (3, 68) < 1]. In addition, words in the Russian phase (*M* = 50.15, *SD* = 72.87) did not differ from words in the first English phase (*M* = 59.18, *SD* = 78.80), t (77) = .53, p = .60, or second English phase (*M* = 62.59.15, *SD* = 90.05), t (75) = .67, p = .51. English stimuli were recorded by a native speaker of English in a sound-proof booth. Russian stimuli were recorded in a similar manner by a native speaker of Russian.

Design and Procedure—The experiment followed a 3 × 4 × 2 design, with Phase (first English phase, Russian phase, second English phase), Phonological Overlap (0-phoneme overlap, 1-phoneme overlap, 2-phoneme overlap, 3-phoneme overlap) and Lexical Status (word, non-word) as within-group factors. The dependent variables measured were latency (measured from stimulus offset) and accuracy of response.

Participants were tested by a fluent Russian-English bilingual, who provided oral instructions in the language appropriate to the experimental phase. Participants heard the stimuli over standard headphones. A set of English items was played first; followed by a set of Russian items, and then a second set of English items. The order of the stimuli in each phase was randomized. On each trial, participants performed a lexical decision task for a phoneme sequence by pressing either a “word” or “non-word” key on the response box. There was a 1500 ms inter-trial interval, and a self-paced break was offered after every 20 trials.

Coding and Analyses—As customary for lexical decision tasks, items with accuracy rates less than 70% across participants were excluded from analyses, resulting in elimination of 9.2% of word data and 10.8% of non-word data. In the word data, 3.33% of eliminated words were in the first English phase, 3.33% were in the Russian phase and 2.5% were in the second English phase. In another 0.9% of the word data and 3.75% of the non-word data, reaction times were greater than 2,500 ms and were substituted with 2,500 ms, which was equal to about 2.5 standard deviations above the reaction time mean across participants. Reaction times above 2,500 ms were substituted (rather than deleted) in order to limit the amount of data excluded and to preserve the extreme scores while scaling down their impact. As customary for lexical decision tasks, follow-up analyses were conducted for word stimuli only. Reaction time and accuracy patterns were examined using 3-way ANOVAs with Phase (first English phase, Russian phase, second English phase), Lexical Status (word, non-word) and Phonological Overlap (0-phoneme overlap, 1-phoneme overlap, 2-phoneme overlap, 3-phoneme overlap) as factors.

Results

Reaction time analyses revealed a main effect of Phase [F (2, 50) = 4.41, p < .05] and a main effect of Lexical Status [F (1, 25) = 56.75, p < .001]. Participants responded faster to words (*M* = 500, *SE* = 31) than to non-words (*M* = 846, *SE* = 65) and were faster in the Russian phase (*M* = 609, *SE* = 50) than in the first English phase (*M* = 711, *SE* = 48), t (25) = 2.95, p < .01, or the second English phase (*M* = 699, *SE* = 54), t (25) = 2.05, p = .051. Significant interactions were found between Phase and Phonological Overlap [F (6, 150) = 4.11, p < .01], between Lexical Status and Phonological Overlap [F (3, 75) = 3.42, p < .05], and between Phase, Lexical Status and Phonological Overlap [F (6, 150) = 4.84, p < .01].

Follow-up analyses showed a main effect of Phonological Overlap in the first English phase [F (3, 75) = 3.18, p < .05], where increased phonological overlap was associated with shorter reaction times (although the relationship was non-linear). Participants responded slower to words with 0-phoneme overlap (*M* = 560, *SE* = 47) than to words with 1-phoneme overlap

(M = 494, SE = 33), t (25) = 2.16, $p < .05$, or to words with 3-phoneme overlap (M = 476, SE = 31), t (25) = 2.61, $p < .05$. Similarly, reaction times to words with 2-phoneme overlap (M = 531, SE = 36) were slower than to words with 3-phoneme overlap, t (25) = 2.98, $p < .01$. Reaction times to words with 1-phoneme overlap and to words with 2-phoneme overlap were not significantly different (p = .06). In the second English phase, no main effect of Phonological Overlap was found. However, planned contrasts showed that reaction times to words with 0-phoneme overlap (M = 568, SE = 51) were slower than to words with 2-phoneme overlap (M = 478, SE = 32), t (25) = 2.73, $p < .05$. No differences in reaction times were found between the first English phase (M = 515, SE = 34) and the second English phase (M = 516, SE = 32), either across stimulus conditions, or at each level of phonological overlap.

In the Russian phase, a main effect of Phonological Overlap was also observed [F (3, 75) = 3.17, $p < .05$]. Contrary to predictions, participants responded slower to words with 0-phoneme overlap (M = 471, SE = 45) than to words with 1-phoneme overlap (M = 393, SE = 38), t (25) = 3.58, $p < .01$, whereas they responded faster to words with 1-phoneme overlap than to words with 2-phoneme overlap (M = 467, SE = 46), t (25) = 3.53, $p < .01$, or with 3-phoneme overlap (M = 539, SE = 58), t (25) = 4.35, $p < .001$ (see Fig. 4).

Accuracy analyses revealed a significant two-way interaction between Phase and Lexical Status [F (2, 50) = 12.53, $p < .001$] and a significant three-way interaction between Phase, Lexical Status and Phonological Overlap [F (6, 150) = 5.12, $p < .001$]. Follow-up analyses did not reveal any significant differences as a function of Phonological Overlap in the first English phase. In the second English phase, participants' accuracy rates were higher for words with 3-phoneme overlap (M = 97%, SE = .01) than for words with 0-phoneme overlap (M = 92%, SE = .02), t (25) = 2.05, p = .051. No differences in accuracy were found between the first English phase (M = 97%, SE = .01) and the second English phase (M = 95%, SE = .01), either across stimulus conditions, or at each level of phonological overlap.

In the Russian phase, accuracy rates were higher for words with 0-phoneme overlap (M = 95%, SE = .01) than for words with 2-phoneme overlap (M = 89%, SE = .03), t (25) = 2.60, $p < .05$, or for words with 3-phoneme overlap (M = 90%, SE = .02), t (25) = 2.60, $p < .05$. Similarly, accuracy rates were higher for words with 1-phoneme overlap (M = 95%, SE = .01) than for words with 2-phoneme overlap, t (25) = 2.29, $p < .05$, or for words with 3-phoneme overlap, t (25) = 2.62, $p < .05$.

Discussion

Results of Experiment 3 confirm that between-language phonological overlap at the sub-lexical level influences speed and accuracy of auditory word recognition in bilinguals. However, different patterns were observed for native and non-native language processing. In the non-native language (English), greater cross-linguistic phonological overlap with the native language was associated with shorter latencies and greater accuracy rates (i.e., facilitation). The opposite pattern was observed for the native language (Russian), where, in general, phonological overlap with the non-native language was associated with longer latencies and decreased accuracy rates (i.e., interference).

In both English (i.e., non-native) phases, words that shared phonology with Russian were identified faster and more accurately than words consisting of unique English phonemes. Moreover, as phonological overlap increased, responses were provided faster and more accurately. Facilitation of the non-native language as a function of phonological overlap with the native language is consistent with previous research reporting facilitation during masked priming of non-native words with phonologically similar native words (Brysbaert et al. 1999).

In the Russian phase, response latency and accuracy were also influenced by degree of phonological overlap. Similar to English processing, lexical decision was slower for Russian words with 0-phoneme overlap than for words with 1-phoneme overlap, suggesting that words with shared phonology were easier to process. However, unlike English word recognition, the effect of phonological overlap on Russian word recognition was not unidirectional. Once a threshold was reached in which detectable cross-linguistic overlap was present, first language processing appeared to be inhibited by increased phonological overlap with the non-native language. Participants responded faster to Russian words with 1-phoneme overlap than to Russian words with 2- or 3-phoneme overlap. Furthermore, participants responded with greater accuracy to words with 0-phoneme overlap than to words with 2- or 3-phoneme overlap, and were more accurate responding to words with 1-phoneme overlap than to words with 2- or 3-phoneme overlap. It appears that lexical decision in the first language is subject to interference effects due to increased phonological overlap with the non-native language. However, lexical decision was slower for Russian words with 0-phoneme overlap than for Russian words with 1-phoneme overlap. This finding is consistent with results from Slowiaczek et al. (2003, Expt. 1, 6) showing that within-language phonological priming during auditory lexical decision may result in facilitation. Slowiaczek et al. suggest that the *percentage* of overlap between targets and competitors may determine whether facilitation takes place, with low-percentage overlap yielding facilitation at the phonological level, and high-percentage overlap yielding inhibition at the lexical level. In the present study, the slower reaction times to words with unique Russian phonemes could be a result of increased activation of English phonology after completion of the lexical decision task in English. It is possible that the English context of the first phase decreased access to uniquely Russian phonological information. Reaction time data reflected this decrease, while accuracy data did not.

The results of the present study are in part similar to those of Jared and Kroll (2001), who also observed interference from the non-native language during native language processing. When English–French bilinguals named English words, French letter-to-sound mappings were activated after participants had completed the French phase of the study (i.e., in the third phase, but not in the first phase). However, unlike our study, Jared and Kroll's (2001) study also showed interference from the native language. French–English bilinguals showed interference for French competitors in the English phases. The different patterns of findings in Jared and Kroll's study compared to the results reported here may be due to modality differences (visual versus auditory), task differences (production versus recognition), and differences in experimental manipulations (letter-to-sound mappings versus degree of sub-lexical phonological overlap).

General Discussion

In three experiments, within- and between-language phonological similarity was manipulated and participants were tested in their native or non-native languages. Experiments 1 and 2 investigated phonological processing in native and non-native languages by testing two bilingual participant groups and keeping the target language constant, while Experiment 3 investigated phonological processing in native and non-native languages by testing one bilingual participant group and varying the target language. Findings suggest that phonological overlap within and between languages influences bilingual language production and recognition.

Summary of Phonological Similarity Effects

In Experiment 1, within-language phonological similarity was manipulated by using words with dense and sparse phonological neighborhoods. German–English (German-native) and English–German (English-native) bilinguals named pictures in German. Results revealed that both bilingual groups named pictures with dense phonological neighborhoods more accurately than pictures with sparse phonological neighborhoods. English–German bilinguals also named pictures with dense phonological neighborhoods faster than pictures with sparse phonological neighborhoods, but German–English bilinguals did not show reaction time differences. These findings suggest that non-native speakers are more sensitive to phonological neighborhood density than native speakers.

In Experiment 2, within-language phonological similarity was manipulated by using stimuli with dense and sparse phonological neighborhoods and between-language phonological similarity was manipulated by using stimuli with onsets that did or did not overlap phonologically across languages. The time-course of lexical co-activation for German competitors (relative to control items) was examined using an English picture identification task. Results showed that both English–German and German–English bilinguals co-activated competitors with low-density neighborhoods more than competitors with high-density neighborhoods. German–English bilinguals co-activated competitors with high-density phonological neighborhoods during an earlier time-window and co-activated competitors with low-density phonological neighborhoods during a later time-window. English–German bilinguals co-activated competitors with low-density phonological neighborhoods during an earlier time-window and did not co-activate competitors with high-density phonological neighborhoods. These findings suggest that while both languages become co-activated during auditory word recognition, the non-native language may be co-activated less. Moreover, the degree and time-course of co-activation varies with extent of within-language phonological overlap, revealing both language-general and language-specific processing mechanisms. In both languages, the degree of co-activation was greater for low-density competitors than for high-density competitors, likely due to higher activation of low-density words, and suggesting that phonological overlap *within* languages may influence extent of co-activation *across* languages. Further, in the low-density condition, onset of parallel activation occurred later in the native than in the non-native language, suggesting that sparse neighborhood size may influence parallel activation of native and non-native languages differently, likely due to a more developed language control mechanism in the native language.

In Experiment 3, between-language phonological similarity was manipulated by constructing stimuli with different degrees of cross-linguistic phonological overlap between native and non-native languages. For a more fine-grained assessment of sensitivity to phonological overlap, degree of overlap was manipulated across four levels (no overlap, 1-phoneme overlap, 2-phoneme overlap and complete overlap). Results of the lexical decision task suggest that cross-linguistic overlap may influence native and non-native word recognition differently. Word recognition in a non-native language appears to be facilitated by phonological overlap with the native language. Word recognition in a native language appears to be inhibited by phonological overlap with the non-native language, but only beyond a certain threshold.

In sum, results of Experiments 1–3 confirm that phonological similarity influences recognition and production differently and that these effects are further modulated by native/non-native language status. Specifically, during language production, increased within-language phonological similarity facilitates picture naming. The facilitation is stronger in the non-native than in the native language (Experiment 1). During language comprehension, high-density phonological neighborhoods are activated only in the native language, while low-density phonological neighborhoods are activated in both languages (Experiment 2). Moreover, sub-lexical phonological overlap with the non-native language inhibits word recognition in the native language, while phonological overlap with the native language facilitates word recognition in the non-native language (Experiment 3). These findings suggest that the influence of one language on the other is asymmetric, and that the nature of this influence (facilitatory or inhibitory) depends on the processing level (lexical or sub-lexical).

Time Course of Bilingual Lexical Access

Comparisons of response latencies across the three experiments allowed a closer examination of the time-course of lexical activation in bilingual language processing. In each of the three experiments, a different paradigm was used. These methodological differences made it possible to consider the time-course of lexical activation across several language tasks. The earliest co-activation of the two languages was observed in Experiment 2, where eye-movements provided a window into the earliest stages of lexical competition. Next, Experiment 3 measured co-activation of the two languages later in the processing stream by using a lexical decision task. Last, Experiment 1 reflected co-activation of the two languages by providing latency measures during production. Therefore, the time-course of lexical co-activation is reported first for implicit measures of early parallel activation (eye-movements, Experiment 2), followed by overt measures of later parallel activation (lexical decision, Experiment 3), and finally by measures of parallel activation at the production stage (naming, Experiment 1).

During auditory word recognition (Experiment 2), co-activation of low-neighborhood *native* competitors occurred between 900 and 1,500 ms post-stimulus onset, co-activation of high-neighborhood native competitors occurred as early as 200 ms post-stimulus onset, co-activation of low-neighborhood *non-native* competitors occurred between 300 and 500 ms post-stimulus onset, and co-activation of high-neighborhood non-native competitors was not observed. The time-course of co-activation differed between native and non-native languages. These findings suggest that the time-course of early lexical activation is influenced by the size of the network of similar-sounding words that becomes co-activated. Further, early lexical activation may be subject to different dynamics and constraints during native and non-native language processing.

During auditory lexical decision (Experiment 3) in the non-native language, lexical access for words with unique non-native phonemes occurred within 1,082–1,092 ms post-stimulus onset, while lexical access for words with phonemes shared between native and non-native languages occurred within 992–1,052 ms post-stimulus onset (The average word duration was 522 ms; although onset data are not typically used in analyses that focus on lexical decision, in this section of the paper onset data will be reported in order to map the time-course of phonological processing across the three experiments and make direct comparisons possible). In the native language, lexical access for words with mostly unique native phonemes occurred within 912–992 ms post-stimulus onset, while lexical access for words with phonemes shared between native and non-native languages occurred within 982–1,062 ms post-stimulus onset. Similarly to Experiment 2, the findings of Experiment 3 showed different patterns of lexical activation in native and non-native languages. Lexical access for words with unique phonology happened earlier during native language processing and later during non-native language processing. In contrast, lexical access for words with shared phonology occurred earlier during non-native language processing and later during native language processing.

During picture naming (Experiment 1), bilinguals named words with large phonological neighborhoods within 2,500 ms post-stimulus onset and words with small phonological neighborhoods within 2,700 ms post-stimulus onset. Native speakers named pictures within 2,100 ms post-stimulus onset, while non-native speakers named pictures within 3,120 ms post-stimulus onset and reaction times were shorter when non-native speakers named pictures with large neighborhoods (3,000 ms) than when they named pictures with small neighborhoods (3,300 ms). Thus, while phonological neighborhood density was found to influence bilingual language processing, its effects were greater during non-native picture naming than during native picture naming.

In sum, during early stages of processing, unfolding auditory input activated various word alternatives within and between languages. The influence of sub-lexical phonological overlap remained apparent until the lexical decision stage. Such gradual activation, leading up to word-selection, is consistent with auditory word recognition models (e.g., Luce and Pisoni 1998; Marslen-Wilson 1987; McClelland and Elman 1986). During naming, phonological similarity was found to influence retrieval of the word's phonological form at the output level. It has been argued that phonological neighborhood effects during naming are evidence for bi-directional feedback between the phonological and lexical levels of word representation (e.g., Dell 1986; Gordon and Dell 2001). Such feedback between levels allows for activated phonological representations to activate lexical representations of phonological neighbors (bottom-up), which in turn strengthen phonological activation of the target to be retrieved (top-down). It was found that the influence of phonological overlap with other words was particularly strong during word retrieval for production in a non-native language. This finding suggests that non-native representations supporting word-form retrieval are less developed, and rely more on the facilitating context of similar-sounding words.

Explaining Native/Non-native Asymmetry

The manipulation of phonological similarity within and across languages revealed an asymmetric pattern of native and non-native processing. This asymmetry may be explained in part by differential segmentation of phonetic representations into phonological categories in native and non-native languages, and may be linked to proficiency levels and manner of second language acquisition. At the lexical level, phonological similarity between words resulted in stronger competition from the native language into the non-native language than vice versa. At the sub-lexical level, native-language overlap facilitated non-native comprehension, but inhibited native-language comprehension.

At the sub-lexical level, a possible explanation for the asymmetry between native and non-native language processing relies on bilinguals' lack of fine-grained distinctions in non-native phonetic representations. For example, research with non-native listeners suggests that auditory word recognition is more difficult in the non-native language than in the native language (e.g., Bradlow and Bent 2002; Takayanagi et al. 2002). Initially, L1 phonological representations may be organized as tightly constrained categories of sounds and include phonological representations for similar L2 categories. For instance, Best (1995) suggested that some L2 phonemes can be perceptually assimilated to L1 phonemic categories, based on commonalities in the place and manner of articulation and voicing. In support of this view, empirical evidence shows poor discrimination of L2 phonemes similar to a common L1 category, compared to L2 phonemes that do not resemble an L1 category (e.g., Best 1995; Imai et al. 2005; Bradlow and Bent 2002). With increased L2 word learning and exposure, phonological representations in the second language may become more fine-grained. However, non-native phonological competence continues to be restricted by age-of-acquisition (e.g., Imai et al. 2005). Imai et al. (2005) studied the mismatch between auditory input and phonological representations in late learners of English. When English words with many phonologically similar neighbors were pronounced with a Spanish accent, Spanish speakers recognized them with greater speed and accuracy than native English speakers. However, when English words were pronounced with an English accent, Spanish speakers with low English proficiency responded slower and less accurately than native English controls and Spanish speakers with high English proficiency. These findings suggest that late learners of English assimilated representations of English phonemes to phonological representations in their native language. In other words, sensitivity to phonological overlap in late learners is asymmetric between native and non-native language-processing due, at least partially, to differences in phonological representations across the two languages, with lower phonological competence in the second language than in the first language.

Empirical evidence suggests that phoneme identification is more difficult for non-native speakers, likely due to greater difficulty discriminating among highly similar phonemes. Poor discrimination of non-native phonological contrasts may be linked to differences in phonological representations between native and non-native speakers. For example, as a result of late acquisition, non-native phonological representations may be organized into wide under-specified categories of sounds, while native phonological representations acquired early in life may be more tightly constrained. This asymmetry in segmenting phonetic space between native and non-native languages may help explain the results obtained in our study. In Experiment 1, the effect of neighborhood size on picture-naming latency was greater for non-native speakers than for native speakers. Inability to identify some phonemes may lead to either an exaggerated or a diminished phonological neighborhood size in non-native speakers. For example, inability to recognize non-native vowel contrasts led to increased co-activation of competitors containing these vowels in Weber and Cutler (2004). Therefore, neighborhood size differences may be greater for non-native speakers than for native speakers (Alternatively, inability to identify certain non-native phonemes may result in a reduced neighborhood size because words containing these phonemes fail to be included in the corresponding phonological neighborhood.) As a result, native and non-native speakers may exhibit different response patterns to dense versus sparse neighborhood targets. In Experiment 2, differences in segmentation of native and non-native phonetic space may have contributed similarly to patterns of competition within native and non-native languages. In Experiment 3, co-activation of native language phonology facilitated processing, perhaps because native language phonemes increased activation of similar non-native phonemes. In contrast, co-activation of non-native language phonology inhibited native-language processing, possibly because non-native phonemes could not activate more constrained native language phonemes. In fact, unique non-native phonemes in the auditory input would be likely to compete with (and diminish the activation of) tightly organized native phonemes. Therefore, cross-linguistic phonological overlap with non-native language led to competition between viable word-form representations and delayed lexical decision in the native language, while cross-linguistic phonological overlap with the native language facilitated lexical decision in the non-native language.

Thus, it appears that differences in native/non-native organization of phonetic space into phonemic categories can at least partially explain native/non-native asymmetries across the three experiments. Such sub-lexical differences may also influence degree of competition at the lexical level. In Experiment 2, where phonological overlap was tied to similarity between lexical entries, lexical-level competition mechanisms were probably present. Similar lexical-level competition was also likely during production in Experiment 1, but may have been weaker, since lexical access had already occurred and retrieval of sub-lexical phonological forms was in progress. However, in Experiment 3, where phonological overlap consisted of language-general phonemes only, lexical-level competition was likely negligible.

Another way to understand differences between neighborhood effects in native and non-native language processing is by examining the developmental path of neighborhood density effects. Namely, developmental research on first-language learning has implications for acquisition processes associated with second language learning. For example, it has been found that while toddlers prefer to listen to high-neighborhood words (Jusczyk et al. 1994), children actually do *worse* at naming high-neighborhood targets compared to low-neighborhood targets (Arnold et al. 2005; Newman and German 2002). This suggests that facilitated naming of high-neighborhood targets may in fact be the end of a developmental path that requires maturation of the language system.

Developmental evidence that neighborhood effects are small at early stages of native language learning and increase as language acquisition progresses may be consistent with acquisition patterns during second language learning (Arnold et al. 2005; Newman and German 2002). It is possible that sensitivity to neighborhood density increases with language proficiency. However, our finding that neighborhood effects are smaller in native speakers than in proficient non-native speakers appear inconsistent with this hypothesis. It may be that the contrast between low- and high-proficiency non-native speakers is different from the contrast between high-proficiency non-native speakers and native speakers. Early second language learners may start out with low phonological awareness and show low sensitivity to phonological neighborhood density compared to native speakers. As second language proficiency increases, so does bilinguals' ability to discriminate non-native phonological contrasts. However, the wider phonological category boundaries in non-native speakers (and, subsequently, the larger neighborhood size) may make these proficient non-native speakers more susceptible to neighborhood density effects compared to native speakers.

In addition to phonological competence and language proficiency, other plausible explanations for the asymmetry between native and non-native language processing may rely on differences in lexical organization and history of language use (e.g., Zevin and Seidenberg 2002; Grosjean 1997). For example, monolingual interlocutors and language settings influence a bilingual's language choice by increasing the use of one language and decreasing its threshold of activation (e.g., Jared and Kroll 2001; Spivey and Marian 1999; Grosjean 1997). As a result, the language used more frequently over an extended period may become dominant and more readily available for processing, and this variability in history of language use may contribute to bilinguals' asymmetry in word recognition and production across languages. Thus, the patterns of results observed in Experiment 1–3 may not hold for bilinguals with a different language-history profile, such as bilinguals who are balanced across both languages, who acquired both languages in parallel, or whose L1/L2 proficiencies differ more drastically.

Implications

Overall, the facilitation and interference effects observed in the present study provide evidence for a non-selective account of bilingual lexical processing. Phonological input overlapping within and across languages influenced bilingual processing dynamics, regardless of the task-relevant language. The findings of the present study underline the important role of phonological similarity in bilingual production and comprehension and suggest a native/non-native asymmetry in bilingual phonological processing. The results have applied implications for bilingual populations in clinical and educational settings.

Specifically, in clinical settings, treatment of bilingual populations with language disorders (such as bilingual aphasia and Specific Language Impairment in bilingual children) may be able to incorporate findings of cross-linguistic L1 facilitation and L2 inhibition, so that one language could be used to 'bootstrap' the other during treatment. For instance, efficiency of treatment for bilingual aphasia with impairments primarily in the second language may be maximized when the starting point for remediation uses second-language words that share greater phonological overlap with the native language (e.g., Roberts and Deslauriers 1999). Similarly, the efficiency of treatment may increase with the use of high-density neighborhood words known to facilitate naming in both languages.

In second language education, word choice for teaching novice learners may be guided by the knowledge that dense-neighborhood words are associated with better performance, while low-neighborhood words need additional support. Similarly, knowing that overlap with the native language facilitates non-native language processing suggests that L2 learners may benefit from linguistic input that shares phonology with their native language. This prediction was recently confirmed in a series of word learning studies, where English monolinguals learned words that either matched or mismatched orthographic and phonological characteristics of English (Kaushanskaya and Marian 2006). Modifying language learning strategies to allow learners to profit from the phonological overlap with their L1 and to pay particular attention to the non-overlapping phonology of their L2 may be particularly beneficial in the initial stages of second language learning.

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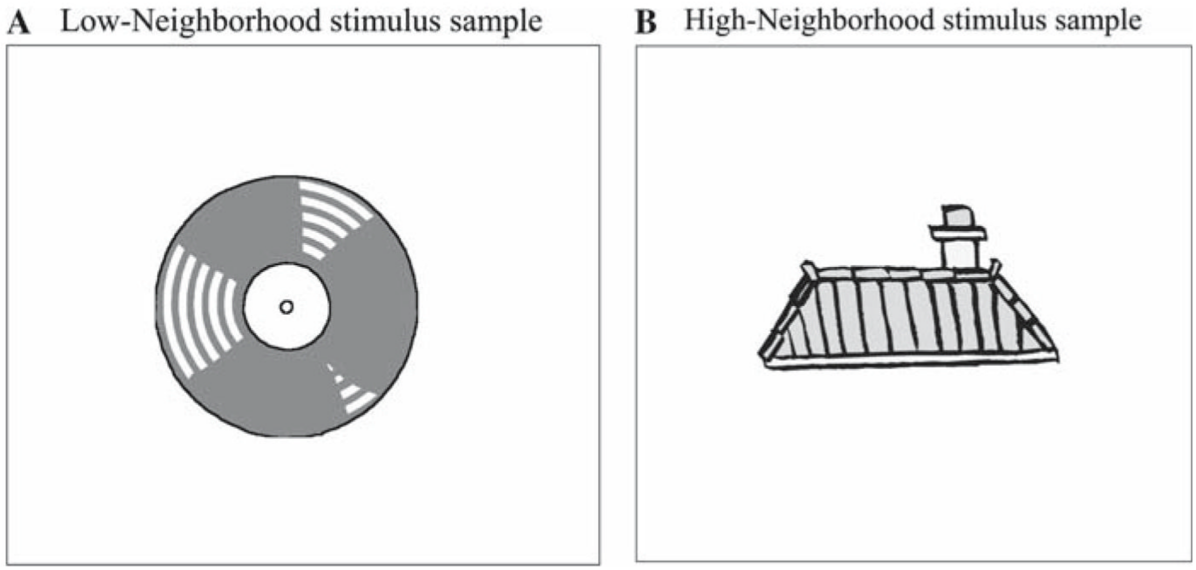

Fig. 1.
Sample stimulus displays for picture naming in Experiment 1. Panel **A** shows an example of a low-neighborhood stimulus, *Platte/record*. Panel **B** shows an example of a high-neighborhood stimulus, *Dach/*roof. Pictures were presented and named one-by-one

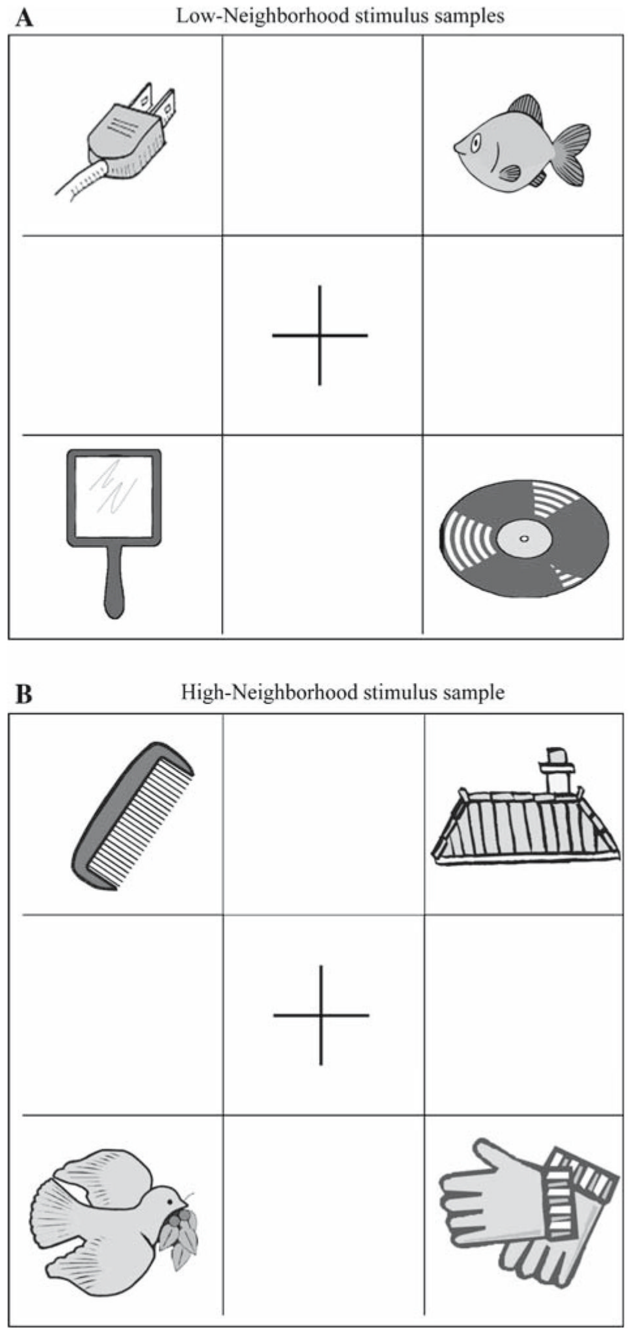

Fig. 2.
Sample stimulus displays for picture identification in Experiment 2. Panel A shows an example of a low-neighborhood competitor, the German word *Platte/*record, which was presented together with the English target *Plug*. Panel B shows an example of a high-neighborhood stimulus, the German word *Dach/*roof, which was presented together with the English target *dove*

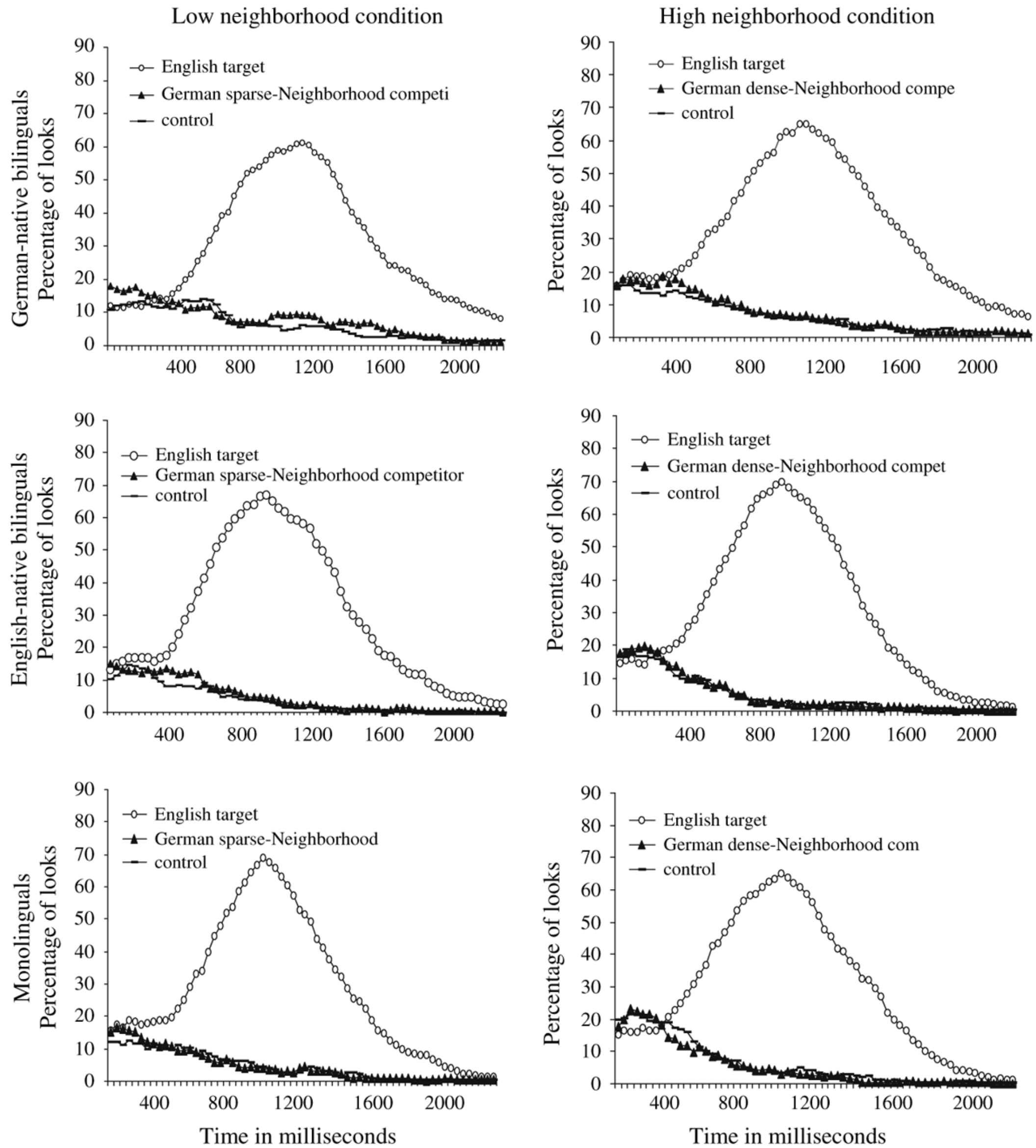

Fig. 3.

Experiment 2: Timecourse of activation for target, competitor and control words in the high- and low-neighborhood conditions

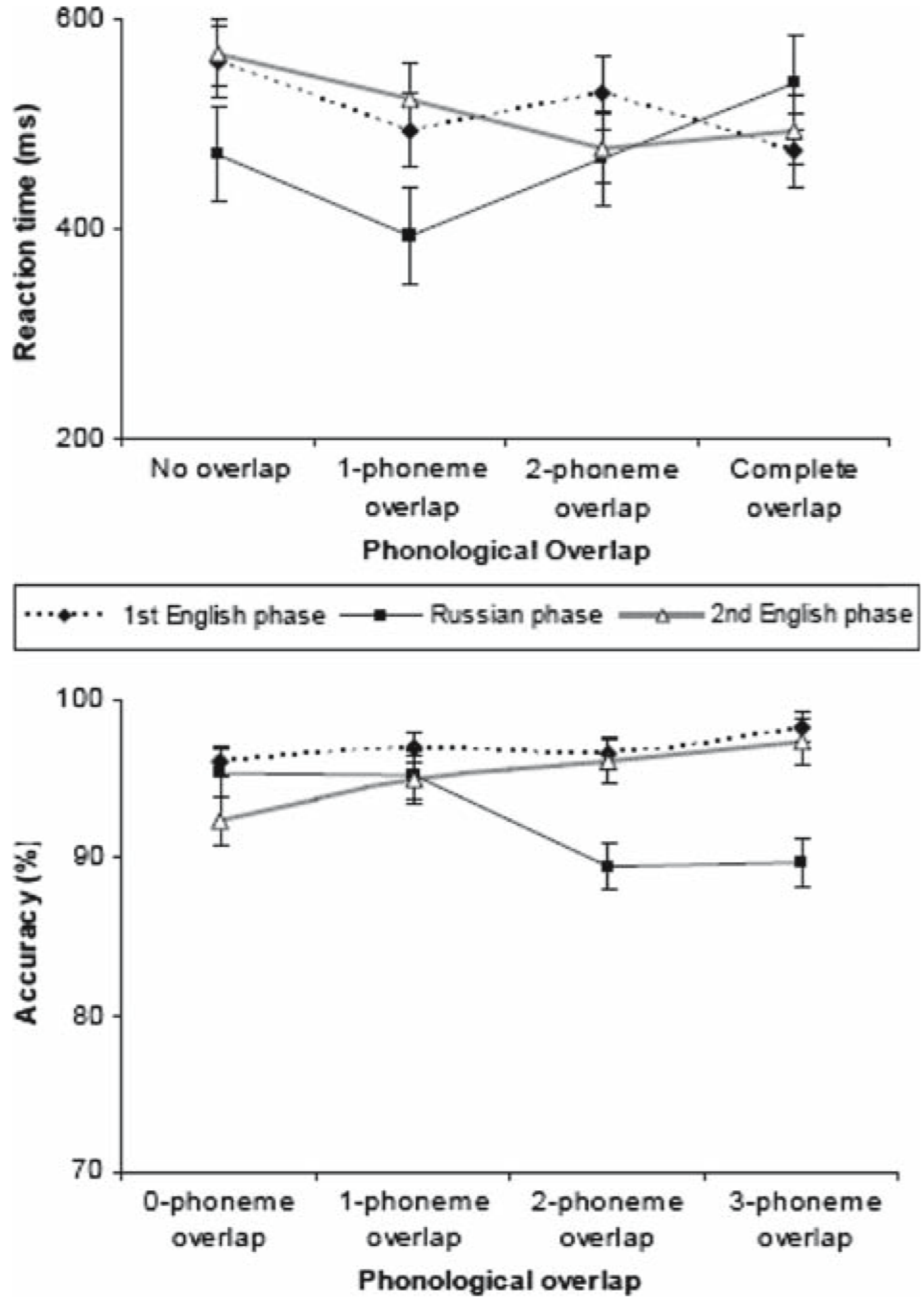

Fig. 4.

Experiment 3: Reaction times and accuracy rates for words across phases and conditions of phonological overlap during lexical decision

Table 1

Stimulus characteristics for high- and low-density neighborhoods

Stimulus characteristics	Descriptive statistics		Inferential statistics
	High phonological neighborhood mean (*SE*)	Low phonological neighborhood mean (*SE*)	
Number of German synonyms	1.30 (0.3)	1.65 (0.3)	t (55) = 0.88, ns
Word length	4.20 (0.3)	4.84 (0.2)	t (55) = 1.71, ns
German frequency	0.51 (0.10)	0.48 (0.11)	t (55) = 0.24, ns
English frequency	0.56 (0.10)	0.44 (0.13)	t (55) = 0.77, ns
German orthographic neighborhood	2.4 (0.68)	2.1 (0.65)	t (55) = 0.41, ns
English orthographic neighborhood	3.1 (0.45)	2.8 (0.70)	t (55) = 0.38, ns