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Phonological neutralization by native and non-native speakers: The case of Russian final devoicing

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ABSTRACT

The present study investigates the extent of word-final devoicing in Russian for three groups of speakers: monolingual native Russian speakers (4 Ss), native Russian speakers with knowledge of English (7 Ss), and American English learners of Russian (9 Ss). Thirty-four minimal pairs of Russian words differing in the underlying voicing of word-final obstruents were recorded. Acoustic analysis focused on four measures: preceding vowel duration, closure/frication duration, duration of voicing into closure/frication, and duration of release portion. Results indicate the absence of complete neutralization of underlying voicing for all three groups. Native Russian speakers showed sizeable differences in each of the four measures. While Russian monolingual speakers produced significant durational differences in closure/frication duration and release duration, native Russians with knowledge of English in addition maintained a difference through vowel duration and duration of voicing into closure/frication. Moreover, correlations indicated that speakers with higher English proficiency produced greater differences for vowel duration. In addition, native speakers of English learning Russian also distinguished final obstruents in terms of preceding vowel duration, closure/frication duration, duration of voicing into closure/frication, and duration of release portion, with greater durational differences for these second language learners than for Russian native speakers. The more proficient speakers of Russian decreased the durational differences and the most proficient second language learners were closer to complete neutralization than monolingual speakers of Russian. The neutralization data will be discussed in terms of the interaction between first and second language in the production of final devoicing.

1. Introduction

Neutralization is the elimination of phonological contrast in certain phonetic environments. One of the most well-studied examples of neutralization is final devoicing, the merger of voiced and voiceless obstruents into voiceless obstruents in word-final position. Word-final devoicing has been extensively researched in a number of languages with mixed results: some studies provided evidence for incomplete neutralization while others challenged this view (Charles-Luce, 1985; Jassem & Richter, 1989; Piroth & Janker, 2004 for German; Port & Crawford, 1989; Port & O'Dell, 1985; Slowiaczek & Dinnsen, 1985 for Polish; Dinnsen & Charles-Luce, 1984; Mascaro, 1987; Charles-Luce & Dinnsen, 1987 for Catalan; Warner, Jongman, Sereno, & Kemps, 2004 for Dutch). The aim of the present study was to examine word-final devoicing in Russian, a language with a relatively large number of word pairs with an underlying voicing distinction for both final stops and fricatives. Native speakers of Russian with and without knowledge of English, a language which does not have final devoicing, were included to address the question of whether a native speaker's knowledge of a second language affects neutralization. A further objective was to investigate final devoicing patterns in the speech of American English learners of Russian.

In languages that do not have word-final devoicing, a number of acoustic cues distinguish word-final voiced from voiceless consonants. These cues are found in the word-final consonant itself as well as in the preceding vowel (Reetz & Jongman, 2009). For example, in English, a voiced word-final stop consonant will typically have a fully voiced closure duration. In contrast, the closure of a voiceless word-final stop consonant will contain no or very brief voicing (e.g., Hogan & Rozsypal, 1980). This closure will also be longer than that of a voiced consonant. In addition to these consonantal cues, the vowel preceding a voiced stop consonant will be longer than that preceding a voiceless consonant. While the difference in most languages is on the order of 20 ms, it tends to be much larger in English, where differences in vowel duration of 50 ms or more are common

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(Peterson & Lehiste, 1960; Chen, 1970). Vowel duration and the presence or the absence of voicing during closure have also been shown to be perceptual cues to the voicing status of the final consonant (e.g., Hillenbrand, Ingrisano, Smith, & Flege, 1984; Raphael, 1972; Wardrip-Fruin, 1982).

In languages with word-final devoicing, phonetic investigations have focused on the cues mentioned above. Some early studies showed that phonetic traces of the underlying phonological distinction are preserved. For example, Port and O'Dell (1985) found that vowels preceding underlying voiced final stops in German were on average 15 ms longer than those preceding underlying voiceless final stops. They also reported more voicing (5 ms) into the underlying voiced stop closure, and longer aspiration (15 ms) for the release of underlying voiceless stops. In a range of production tasks in German, Port and Crawford (1989) found that across speakers and conditions only duration of the release burst of the final stops could differentiate between underlying voiced and voiceless final consonants.

In Russian, Pye (1986) found that vowels were 5–20 ms longer when preceding underlying voiced final obstruents, and the final obstruents themselves were 6–30 ms longer when underlyingly voiceless. Pye reported that duration of the vowel distinguished underlying voiced from underlying voiceless final obstruents more consistently than duration of the obstruent but no statistical analyses were reported. Underlying voiced final obstruents showed overall longer intervals of voicing during closure, although there was considerable inter-speaker variation.

However, Charles-Luce (1985) showed that the German final voicing contrast can be completely neutralized in some sentential and phonetic environments. Slowiaczek and Dinnsen (1985) also showed for Polish that although vowels were on average 10 ms longer before underlying voiced final obstruents than before underlying voiceless ones, the way in which underlying distinctions were preserved was highly dependent on phonetic environment and individual speakers. To specifically examine speaker differences, Jassem and Richter (1989) re-analyzed Polish final devoicing. Unlike Slowiaczek and Dinnsen (1985), they used speakers of the same dialect of Polish who did not know any foreign languages. The experiment was conducted as a spontaneous dialogue with a high degree of naturalness. No significant differences between underlying voiced and voiceless final obstruents were found.

Addressing speaker differences, Piroth and Janker (2004) identified a number of problems with previous studies, including the use of a very small number of stimuli, the use of archaic forms, and the use of word pairs that show a final voicing distinction in their orthography but have in fact the same underlying representation. Piroth and Janker (2004) conducted a well-controlled study in which 6 speakers from various regions of Germany produced minimal word pairs in several positions, including non-neutralizing, syllable-final, and word-final positions. For words ending in stops, Piroth and Janker (2004) analyzed vowel duration, voicing into closure, coda duration (closure duration+release duration), and rhyme duration (vowel duration+coda duration). Statistics provided for each individual speaker showed that the underlying voicing of the word-final consonant did not affect any of these measures for any of the speakers, with one exception. The two speakers from Southern Germany had significantly longer coda durations for underlying voiceless consonants.

Warner et al. (2004) conducted a large-scale study of word-final devoicing in Dutch. They established that vowels were approximately 3.5 ms longer before underlying voiced final consonants and the burst was 9 ms longer for underlying voiceless final consonants but only when following phonemically long vowels. Warner et al. (2004) also found that listeners can use these subtle acoustic differences to distinguish words with different underlying forms but that this ability is highly dependent on the pattern of differences individual speakers produce. Warner et al. (2004) concluded that a variety of factors, in addition to underlying form, can yield significant and pervasive durational differences.

In their study of German final devoicing, Fourakis and Iverson (1984) established that the nature of the task also affected the results. In particular, while results of a reading task showed incomplete neutralization, results of an elicitation task showed complete neutralization. Fourakis and Iverson (1984) concluded that incomplete neutralization arises from hypercorrection due to linguistically unnatural conditions of reading tasks. Wissing and Van Rooy (1992) observed similar results in their study of final devoicing in Afrikaans: in a sentence task, closure duration of the final stop was different for underlying voiced and voiceless segments but in a direction opposite to that expected, while in a wordlist task, vowels were longer before underlying voiced final stops, as expected. Van Rooy (2003) concluded that when the participants were encouraged by pragmatic conditions to produce a difference between the members of the minimal pairs, they were able to maintain a distinction between underlying voiced and voiceless final stops in all the acoustic parameters measured: vowel duration, aspiration duration, closure duration, and duration of voicing into closure. Otherwise this phonetic distinction was completely neutralized.

Dinnsen and Charles-Luce (1984) studied voicing neutralization in Catalan, a language that in contrast to Dutch, German, Russian, Polish, and Afrikaans, does not indicate the underlying phonological distinction orthographically. Group results showed evidence for complete neutralization of word-final consonants, similar to the results of Kopkalli (1993) for Turkish, another language that does not reflect underlying voicing distinctions orthographically.

However, Charles-Luce and Dinnsen (1987), in their re-analysis of their original Catalan findings, provided data supporting incomplete neutralization, showing that voicing into closure was longer for underlying voiced final stops than for underlying voiceless ones. Interestingly, in their analysis of the individual data, Charles-Luce and Dinnsen observed that some speakers maintain underlying voicing distinctions in different ways. One speaker produced underlying voiced final stops that were much shorter than underlying voiceless final stops, while another speaker produced shorter vowels before underlying voiceless final stops.

The set of studies discussed above shows that the extent of word-final devoicing may vary due to individual speaker characteristics and task as well as which acoustic cue is measured. The present study examined a relatively unexplored individual difference, namely second language knowledge, as a possible variable that may affect neutralization. In the previous literature, Jassem and Richter (1989) had criticized Slowiaczek and Dinnsen (1985) for using Polish subjects who lived in an English-speaking country as well as for the lack of control for second language proficiency. To remedy this, Jassem and Richter (1989) recruited their subjects among monolingual speakers of Polish with no knowledge of any other language, showing a much smaller effect of underlying voicing than Slowiaczek and Dinnsen (1985). While the differences in underlying voicing reported in the previous research could be due to second language interference, proficiency in a second language has not typically been controlled for or manipulated in studies of neutralization.

Port and Crawford (1989) made an effort to reduce possible language interference: their subjects were exchange students from Germany whose visit to the US was only 3 weeks long. None of them had ever lived in an English-speaking country for more than a month and their spoken English was judged by the experimenters as "not good". Charles-Luce (1985) reported that

her German subjects lived in the US but for no longer than 2.5 years. No information was given as to the English proficiency of the subjects. Four subjects out of five in Pye's (1986) study of Russian had lived in England for between 2 and 10 years, the fifth was a 3-week visitor from the former Soviet Union. Pye neither comments on their English proficiency nor attempts to correlate their variable amount of exposure to English with their extent of final devoicing. Warner et al. (2004) were aware of the necessity to avoid subjects who had exposure to a language which lacks final devoicing, such as English. Although they minimized the possibility of language interference by recruiting their subjects and conducting the experiment in The Netherlands, all participants were reasonably familiar with English since learning English is an integral part of education in the country.

A recent study by Simon (2010) investigated the extent to which native speakers of Dutch transfer devoicing to their second language (L2) English productions. The primary focus of this study was on conversational speech obtained from 8 pairs of Dutch participants having a conversation in English. These participants were all studying English at the university and had taken extensive English pronunciation sessions in the year before the recording session. Word-final obstruents were coded as voiced or voiceless based on auditory impression. Results show that the majority (59%) of underlying voiced stops were produced as voiced. A small word-reading task with 10 speakers and 5 words ending in a voiced stop was also included. In this task, 84% of word-final voiced stops were perceived as voiced by the author. Finally, acoustic measurements of the vowel duration in three minimal pairs (e.g., *bet-bed*) showed that the vowel was substantially and significantly longer (by 76 ms on average) when preceding voiced as compared to voiceless stops. Overall, then, these proficient learners of English devoiced voiced stops in 41% of the tokens in spontaneous conversation and in 16% of the tokens in a word-reading task. In order to directly compare these results to other investigations of devoicing, it would be necessary to subject these recordings to detailed acoustic analyses since previous acoustic studies have often found consistent significant differences between words ending in underlying voiced and voiceless stops that are too small to be perceived (e.g., Warner et al., 2004).

The goal of the present study is therefore three-fold. First of all, it seeks to provide a more comprehensive investigation and analysis of the acoustic correlates of Russian final devoicing. Four measures most commonly found to correlate with consonant voicing were analyzed: duration of the vowel preceding the final obstruent, duration of the final obstruent (either closure duration for stops or frication duration for fricatives), duration of voicing into closure/frication portion of the final obstruent, and duration of the release portion of the final stop. The present study makes use of the experimental task employed by most previous studies, wordlist reading, to allow for control over intonational effects and for a direct comparison with previous studies in other languages. A large number of target words were recorded in the experiment, including a comprehensive set of Russian word pairs differing in the underlying voicing of the final consonant (both stops and fricatives), exhibiting productive devoicing in Russian. In addition, many fillers were inserted in the word list to prevent the participants from guessing the purpose of the experiment. The only available study of Russian word-final devoicing, Pye (1986), offers only preliminary results and leaves many questions unanswered; no statistical analysis was performed and numerical results were only reported as ranges.

Second, this study explores the extent to which knowledge of English as a second language affects production of final devoicing for native Russian speakers. While a number of studies have documented speaker differences in neutralization, most studies of neutralization do not take into account speakers' proficiency in other languages and the extent to which this may affect their productions. The present study also systematically examined L2 experience in English to determine its effect on neutralization in Russian. As evidence from previous research on final devoicing indirectly suggests, the use of subjects with knowledge of a language that lacks final devoicing (e.g., English) may result in language interference and affect the outcome of the study. No study on word-final devoicing, however, has directly compared monolingual speakers with speakers who possess some knowledge of English. The present study is the first to investigate a possible correlation between English proficiency and extent of final devoicing for Russian participants.

Finally, this study investigates the second language acquisition of word-final devoicing by learners of Russian whose native language does not have final devoicing. While neutralization has been investigated in detail in the speech of native speakers, it is not clear if and at which stage such processes are mastered by L2 learners. Specifically, American English learners' acquisition of Russian final devoicing is investigated. This study thus provides a detailed analysis of word-final devoicing in Russian, examining both native Russian speakers and American English learners of Russian.

2. Acoustic study

2.1. Method

2.1.1. Stimuli

The stimuli consisted of 34 word pairs contrasting in the underlying voicing of the final obstruent. The Russian orthography reflects the underlying differences as illustrated in the minimal pairs: КОД /kod/ [kot] (*code*)–КОТ /kot/ [kot] (*cat*) and без /bez/ [bes] (*without*)–бес /bes/ [bes] (*devil*). There were 32 minimal pairs and 2 near-minimal pairs (e.g., /grab/–/drap/). All tokens were real Russian words. Frequency of occurrence of the voiced and unvoiced pairs was calculated using a frequency database based on the large corpus of Russian (Ljashovskaja & Sharov, 2008, Russian National Corpus). Frequency of the stimuli ending in underlyingly voiced consonants (*M*: 135 per million) was not significantly different from the frequency of those ending in underlyingly voiceless consonants (*M*: 126 per million) ($t(33)=.096$, $p=.924$, ns). Half of the pairs ended in stops, the other half ended in fricatives. Final obstruents at all places of articulation present in Russian were included: bilabial, dental, and velar stops as well as labiodental, alveolar, and post-alveolar fricatives. The word pairs were selected with the goal of representing the maximum variety of vowels and final consonants. Twenty-five of the pairs consisted of monosyllabic CVC words, 7 pairs of CCVC words, and 2 pairs of VCVC words. Tokens were arranged in a wordlist with an additional 58 filler items with semantic associations to conceal the purpose of the experiment from the participants. For example, the word /zub/ (*tooth*) was preceded by the filler /glaz/ (*eye*), and the word /trup/ (*corpse*) was followed by the filler /mrut/ (*die*, 3^{d} person plural). Members of each stimulus pair were always at least 4 words apart in the wordlist.

2.1.2. Participants

2.1.2.1. Russian native speakers. Eleven native speakers of Russian (one male and 10 female) participated in the experiment. Their age ranged from 20 to 40 years. None had a known history of speech or hearing disorders. Seven of the participants were native Russian speakers who were living in the US They were all recorded in the US. Most of them were students or short-term

visiting researchers at the University of Kansas. Two of them lived permanently in the US, were married to US citizens, and worked at the University of Kansas. They were all born in Russia and had lived there during their childhood. The earliest age of arrival in the US was 16. By the time of the experiment, participants had lived in the US from one to 10 years. Consequently, they had a varied amount of exposure to English and varied English proficiency. The remaining four speakers were recorded in Russia. These participants did not have significant exposure to English or any other foreign language. All Russian participants who lived in the US were given a second language questionnaire. The purpose of the questionnaire was to establish the amount of formal English instruction they had received, the duration of their residence in English-speaking countries, and the quality of their social ties to the English-speaking community. In addition, they were asked to rate their English grammar and pronunciation each on a 5-point scale: 1—very poor, 2—poor, 3—average, 4—good, 5—excellent. The resulting self-ratings ranged from 6 to 10 points, with four participants reporting excellent or good knowledge and three participants reporting average knowledge of English. The monolingual speakers recorded in Russia were automatically assigned a rating of 0.

2.1.2.2. American English learners of Russian. Nine native speakers (8 male and 1 female) of American English learning Russian participated in the experiment. Their age ranged from 20 to 60 years. None of the participants had a known history of speech or hearing disorders. Five of the participants were students studying Russian at the University of Kansas. Three were professors teaching Russian courses in the Slavic department. One participant was a family member of one of the professors of Russian. This participant learned Russian through frequent trips to the country and interactions with Russian friends and acquaintances in addition to studying Russian in an academic setting. Parallel to the evaluation of the Russian participants, all American learners of Russian were given a second language questionnaire to assess the amount of formal Russian instruction they had received, the duration of their residence in Russian-speaking countries, and the quality of their social ties to the Russian-speaking community. They were also asked to rate their Russian grammar and pronunciation each on a 5-point scale from very poor (1) to excellent (5). Participants ranged between 2 and 10 points in their self-estimated knowledge of Russian. Three participants reported good or excellent knowledge, four reported average knowledge, and two reported poor or very poor knowledge of Russian.

2.2. Procedure

Subjects were instructed to read the wordlist three times in a tempo comfortable for them. The two readings containing no mispronunciations or disfluencies as judged by the first author were used for analysis. For the native Russian speakers, the first two readings were used in most cases. When a member of a pair was mispronounced, the whole pair was replaced by the pair from the third reading. The American English learners of Russian were encouraged to examine the list before recording began. Some of the less proficient American L2 learners made occasional pronunciation mistakes, especially during the first reading. Therefore, for the American English speakers, the last two readings were used in most cases.

The recordings in the US were made in an anechoic chamber at the University of Kansas using a Fostex D-5 DAT recorder and an Electrovoice RE-20 microphone. The recordings in Russia were made using a portable Sony PCM-M1 DAT recorder and an Electrovoice N/D767a microphone. Recordings were digitized at a sampling rate of 22,050 Hz using MultiSpeech software. A total of 136 tokens (34 pairs $\times$ 2 repetitions) were analyzed for each speaker. Tokens were number-coded to avoid experimenter bias.

Four measures were analyzed: duration of the vowel preceding the final obstruent, duration of the final obstruent (closure duration for stops and frication duration for fricatives), duration of voicing into closure/frication portion of the final obstruent, and duration of the release portion of the final stop. Vowels were measured from the onset of the first formant in the spectrogram, or the sudden discontinuity in the spectrogram for the vowels following nasals and liquids, until the end of the second formant and the abrupt drop in waveform amplitude. Stop closure duration was measured from the end of the vowel until the beginning of the release portion. Frication was measured from the end of the vowel until the end of frication noise in the spectrogram. Voicing into closure/frication was measured from the end of the vowel until the end of periodic vibrations in the waveform. The duration of the release portion of the final stop was measured from the onset of sudden discontinuity in the waveform and spectrogram until the end of the visible noise in the spectrogram. For each measure, values were averaged across the two productions of each word for each speaker.

2.3. Results

To assess the contribution of different speaker groups to final devoicing, two-way repeated measures ANOVAs with Underlying Voicing and Participant Group (native Russians with no English, native Russians with English experience, and American English learners of Russian) as factors were conducted for all four dependent variables. A significant main effect of Underlying Voicing was found for all four dependent variables. As a group, speakers distinguished final obstruents contrasting in underlying voicing for vowel duration ($F(1, 17)=11.336$, $p=.004$), closure/frication duration ($F(1, 17)=26.220$, $p<.001$), duration of voicing into closure/frication ($F(1, 17)=6.403$, $p=.02$), and release duration ($F(1, 17)=5.967$, $p=.02$). For all speakers, vowel duration was longer, closure/frication duration was shorter, the voicing into closure was longer, and the release portion was shorter for words ending in underlying voiced obstruents. Most interestingly, there was a significant interaction between Underlying Voicing and Participant Group for vowel duration ($F(2, 17)=6.292$, $p=.009$) and voicing into closure/frication duration ($F(2, 17)=3.450$, $p=.05$) as well as a trend observed for closure/frication duration ($F(2, 17)=2.660$, $p=.099$). Monolingual Russians, Russians with English, and American English learners of Russian varied in terms of the produced differences between underlying voiced and voiceless obstruents. To further investigate the durational parameters involved in distinguishing underlying voiced and voiceless final obstruents by speakers of different groups, separate analyses of each participant group were undertaken.

2.3.1. Russian speakers

The acoustic measures of all native Russian speakers were analyzed together in a series of separate paired *t*-tests with Underlying Voicing as the independent variable and vowel duration, closure/frication duration, voicing into closure/frication duration, and release portion duration as dependent variables.

A significant main effect of Underlying Voicing was found for all four dependent variables (see Table 1). Vowels were on average 6 ms longer when preceding underlying voiced final obstruents (153 ms) compared to voiceless final obstruents (147 ms) ($t(10)=3.025$, $p=.013$). Closure/frication portion of the final obstruent was on average 16 ms shorter for underlying

Table 1
Mean durations (in ms) and standard deviations (in parentheses) for preceding vowel duration, closure/frication portion, voicing into closure/frication portion, and release portion of words ending in underlying voiced and voiceless consonants for all native speakers of Russian. Δ reflects the average difference for each measure between voiced and voiceless tokens.

	Voiced	Voiceless	Δ
Vowel	153 (13)	147 (14)	6**
Closure/frication portion	165 (22)	181 (22)	−16***
Voicing into closure	27 (7)	23 (5)	4*
Release portion	98 (24)	116 (29)	−18***

* Indicates $p < .05$.
** Indicates $p < .01$.
*** Indicates $p < .001$.

voiced consonants (165 ms) as compared to underlying voiceless consonants (181 ms) ($t(10)=6.748$, $p < .001$). Duration of voicing into closure/frication portion was on average 4 ms longer for underlying voiced final obstruents (27 ms) as compared to underlying voiceless consonants (23 ms) ($t(10)=2.762$, $p=.020$). Duration of the release portion of final stops was on average 18 ms shorter for underlying voiced consonants (98 ms) as compared to underlying voiceless consonants (116 ms) ($t(10)=4.948$, $p=.001$). Russian speakers distinguished final obstruents contrasting in underlying voicing for all measures.

2.3.2. Russian speakers and the influence of English as a second language

To assess the contribution of exposure to English to final devoicing, two-way repeated measures ANOVAs with Underlying Voicing and Knowledge of English as factors were conducted for all four dependent variables.

For each of the dependent variables, there was a significant main effect of Underlying Voicing for the Russian native speakers as detailed above. There was also a significant main effect of Knowledge of English for voicing into closure/frication duration. On average, the period of voicing into closure/frication portion was 8 ms longer ($F(1, 9)=7.744$, $p=.021$) for speakers of Russian with knowledge of English as compared to monolingual speakers of Russian. However, there were no significant interactions of Underlying Voicing and Knowledge of English for vowel duration, closure/frication duration, voicing into closure/frication duration, and release portion duration. Table 2 shows the durations for underlying voiced and voiceless consonants for Russian speakers with and without knowledge of English. It seems that speakers of Russian with knowledge of English produced similar duration differences between underlying voiced and voiceless obstruents as compared to monolingual Russian speakers.

However, our speakers of Russian with knowledge of English varied in terms of their experience with English, with four speakers having studied English for 10 or more years. When these most experienced speakers of English were compared to the native Russian speakers with no English, there was a significant interaction between Underlying Voicing and Knowledge of English for vowel duration ($F(1, 6)=11.444$, $p=.015$) and voicing into closure/frication duration ($F(1, 6)=7.534$, $p=.034$). Russian speakers who are most experienced in English produced significantly greater differences between underlying voiced and voiceless obstruents in terms of vowel duration and voicing into closure/frication duration as compared to monolingual Russian speakers.

To better understand which durational parameters played a role in distinguishing underlying voiced and voiceless final obstruents for the two groups of Russian speakers (Russians with knowledge of English and monolingual Russian speakers), separate paired *t*-tests were conducted for each group with Underlying Voicing as an independent variable and vowel duration, closure/frication duration, voicing into closure/frication duration, and release portion duration as the dependent variables. Results showed that for the group of Russian speakers with knowledge of English, all four parameters were significantly affected by Underlying Voicing. Vowels were on average 8 ms longer when preceding underlying voiced final obstruents ($t(6)=2.929$, $p=.026$) as compared to voiceless obstruents, closure/frication portion was on average 15 ms shorter for underlying voiced final obstruents ($t(6)=4.430$, $p=.004$) as compared to voiceless obstruents, voicing into closure was on average 6 ms longer for underlying voiced final obstruents ($t(6)=2.618$, $p=.040$) as compared to voiceless obstruents, and release portion was on average 17 ms shorter for underlying voiced final stops ($t(6)=3.386$, $p=.015$) as compared to voiceless obstruents.

Table 2
Mean durations (in ms) and standard deviations (in parentheses) for vowel, closure/frication portion, voicing into closure/frication portion, and release portion of words ending in underlying voiced and voiceless consonants for Russian speakers without knowledge of English (Russian) and with knowledge of English (Russian with English) in Experiment 1. Δ reflects the difference for each measure between voiced and voiceless tokens.

	Russian			Russian with English		
	Voiced	Voiceless	Δ	Voiced	Voiceless	Δ
Vowel	142 (14)	140 (17)	2	159 (8)	151 (11)	8*
Closure/frication	166 (16)	182 (13)	−16**	165 (26)	180 (27)	−15**
Voicing into closure	21 (1)	20 (1)	1	31 (7)	25 (5)	6*
Release portion	93 (20)	109 (15)	−16*	102 (27)	119 (35)	−17**

* Indicates $p < .05$.
** Indicates $p < .01$.

However, for the group of Russian speakers without knowledge of English, there were no significant main effects for vowel duration and duration of voicing into closure/frication. For these monolingual Russian speakers, the difference in vowel duration was only 2 ms in the expected direction and the difference in duration of voicing into closure/frication portion was only 1 ms in the expected direction. These differences were not statistically significant. However, the duration of the closure/frication portion was 16 ms shorter for underlying voiced final obstruents ($t(3)=6.061$, $p=.009$) and duration of the release portion was 16 ms shorter for underlying voiced final stops ($t(3)=4.018$, $p=.028$), both significant differences. For the group of monolingual Russian speakers, there were significant effects only for duration of the closure/frication portion as well as release portion of final stop consonants.

Thus, speakers of Russian with knowledge of English made use of all the durational parameters measured in the present study. Vowel duration was longer, closure/frication duration was shorter, the voicing into closure was longer, and the release portion was shorter for words ending in underlying voiced obstruents. Monolingual speakers of Russian with no English knowledge, however, preserved the distinction between underlying voiced and voiceless final obstruents mainly through manipulating the duration of the closure/frication and release portion.

2.3.3. American English learners of Russian

For the L2 learners, separate paired *t*-tests with Underlying Voicing as the independent variable were conducted for all four dependent variables. These analyses revealed that vowel duration,

Table 3
Mean durations (in ms) and standard deviations (in parentheses) for vowel, closure/frication portions, voicing into closure/frication portion, and release portion of words ending in underlying voiced and voiceless consonants for American English learners of Russian. Δ reflects the difference for each measure between voiced and voiceless tokens.

	Voiced (ms)	Voiceless (ms)	Δ
Vowel	181 (47)	144 (21)	37**
Closure/frication portion	196 (21)	230 (25)	−34**
Voicing into closure	53 (28)	26 (6)	27*
Release portion	126 (54)	133 (62)	−7

* Indicates $p < .05$.
** Indicates $p < .01$.

duration of closure/frication itself, and duration of voicing into closure/frication portion were significantly affected by the underlying voicing of the final obstruent (see Table 3). Vowels were 37 ms longer when preceding underlying voiced final obstruents ($t(8)=3.962$, $p=.004$). For underlying voiced final obstruents, closure or frication portion was 34 ms shorter ($t(8)=4.131$, $p=.003$). There was a 27 ms longer period of voicing into closure/frication for underlying voiced final obstruents ($t(8)=2.934$, $p=.019$). While the release portion was 7 ms shorter for underlying voiced final stops, this difference was not significant. The pattern of results showed that native speakers of American English who are learning Russian produced significant durational differences, including vowel, closure/fricative, and voicing into closure/fricative, between the members of Russian minimal pairs that reflect the underlying voicing of the final obstruent.

2.3.4. Native speakers of Russian vs. L2 learners of Russian

To determine whether there was a statistically significant difference in the production of final devoicing between Russian native speakers and learners of Russian, a two-way repeated measures ANOVA with Underlying Voicing and Native Language as independent variables was conducted for the Russian native speakers and the American English learners of Russian. As a group, the Russian native speakers and the American English learners of Russian show significant differences due to underlying voicing of the final obstruent in all the durational parameters measured in the present study. Vowel duration was longer, closure/frication duration was shorter, voicing into closure was longer, and the release portion was shorter for words ending in underlying voiced obstruents.

There was also a significant main effect of Native Language for closure/frication duration and for voicing into closure/frication: when produced by learners of Russian, closure/frication portion was 40 ms longer ($F(1, 18)=18.588$, $p < .001$) and voicing into closure/frication portion was 14 ms longer ($F(1, 18)=9.359$, $p=.007$). For these measures, tokens produced by learners of Russian were significantly longer than those produced by native speakers of Russian.

Most interestingly, there was a significant interaction between Underlying Voicing and Native Language for vowel duration ($F(1, 18)=12.990$, $p=.002$), closure/frication duration ($F(1, 18)=5.626$, $p=.029$), and voicing into closure/frication duration ($F(1, 18)=7.101$, $p=.016$). As shown in Fig. 1, American English learners of Russian produced greater differences between underlying voiced and voiceless obstruents as compared to native Russian speakers.

2.3.5. Analysis of effect of L2 experience

2.3.5.1. Russian native speakers. The data above suggest that cues for word-final voicing may be influenced by speakers' knowledge of second language phonological processes. For Russian speakers, knowledge of a second language which lacks final devoicing can lead to significant differences in production in their native language. To further examine the extent to which knowledge of English affects neutralization for native Russian speakers, L2 experience in English was examined. To investigate whether more fine-grained differences in English experience and proficiency could be shown to play a role in the production of final devoicing, Pearson correlation analyses were conducted. For each acoustic parameter, the durational difference between underlying voiced and voiceless final obstruents was calculated for each token. For each word pair differing underlyingly in final voicing, the duration of the vowel preceding the underlying voiceless final obstruent was subtracted from the duration of the vowel preceding the underlying voiced final obstruent. A similar procedure was applied to closure/frication duration, voicing into closure/frication and release portion duration.

The results of the second language questionnaire were also quantified to obtain an individual L2 Experience Score for each participant. This score consisted of the sum of the following two components: the number of years studying English ($M=7.3$ years, sd = 3.82, range 1–12 years) and the number of years spent in an English-speaking country ($M=4.1$ years, sd = 3.39, range 1–11 years). For the monolingual speakers of Russian, these two components were given a value of zero since none of them had studied English or spent any time in an English-speaking country. For the Russian speakers, then, the overall L2 Experience Scores ranged from 0 to 19 (i.e., least English knowledge to most English knowledge: $M=7.3$ years, sd = 7.32).

For the Russian speakers, durational differences for each parameter were then correlated with the L2 Experience Scores. One of the dependent variables showed a significant correlation: vowel duration. There was a significant positive correlation (see Fig. 2) between the L2 Experience Score and the durational difference between the vowel preceding underlying voiced and voiceless final obstruents ($r(11)=.681$, $p=.021$, $r^2=.46$).[1] This correlation showed that vowel duration differences between voiced and voiceless final obstruents increased as the native Russian speakers' experience in English increased.

2.3.5.2. American English learners of Russian. A Pearson correlation similar to the one performed for native speakers of Russian was conducted with the American learners of Russian to determine whether Russian proficiency affected their production of final obstruents in Russian. L2 Experience Scores were calculated in a similar fashion for the learners of Russian, consisting of the sum of the number of years studying Russian ($M=11.4$ years, sd = 15.33, range 1–47 years) and the number of years spent in a Russian-speaking country ($M=1.7$ years, sd = 1.80, range 0–5 years). For the American English speakers, then, the overall L2 Experience Scores ranged from 1 to 52 (i.e., least Russian knowledge to most Russian knowledge: $M=13.1$ years, sd = 16.83).

These L2 Experience Scores were correlated with the durational differences measured between underlying voiced and voiceless final obstruents. The results for the L2 learners of Russian revealed a significant correlation between L2 experience and production of final devoicing (see Fig. 3). There was a significant negative correlation for vowel duration ($r(9)=-.708$, $p=.033$, $r^2=.50$), and a strong trend observed for both closure/frication duration ($r(9)=.645$, $p=.06$, $r^2=.42$) and duration of voicing into closure/frication ($r(9)=-.573$, $p=.10$, $r^2=.33$).[2]

[1] The significant correlation also held if vowel duration was correlated with self-ratings of grammar and pronunciation proficiency ($M=5.2$, sd = 4.33) ($r(11)=.603$, $p=.05$, $r^2=.36$), rather than the L2 Experience Score.

[2] The significant correlations also held if vowel duration and duration of voicing into closure/frication were correlated with self-ratings of grammar and pronunciation proficiency ($M=6.4$, sd = 2.35) ($r(9)=-.673$, $p=.05$, $r^2=.45$; $r(9)=-.848$, $p=.004$, $r^2=.72$, respectively), rather than the L2 Experience Score.

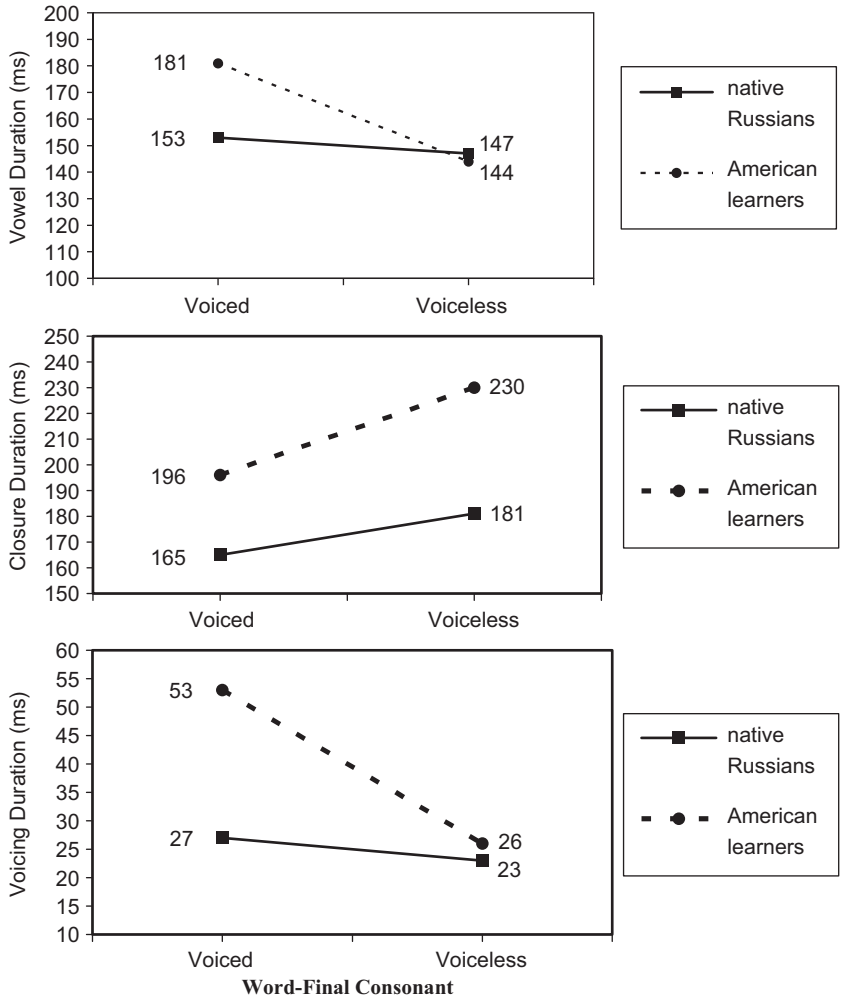

Fig. 1. Vowel duration (ms) (top panel), closure/frication duration (ms) (middle panel), and voicing into closure/frication duration (ms) (bottom panel) as a function of the underlying voicing of word-final consonants in native Russian speakers and American learners of Russian.

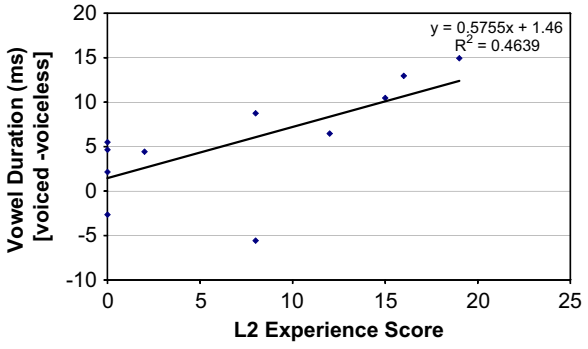

Fig. 2. Scatterplot of vowel duration differences (vowel duration preceding underlying voiced obstruents minus vowel duration preceding underlying voiceless obstruents) as a function of L2 experience in English for Russian native speakers.

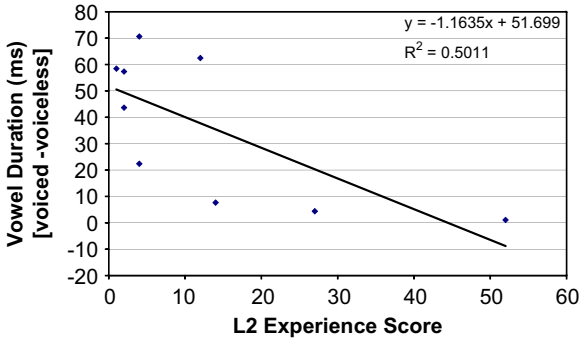

Fig. 3. Scatterplot of vowel duration differences (vowel duration preceding underlying voiced obstruents minus vowel duration preceding underlying voiceless obstruents) as a function of L2 experience in Russian for native speakers of English who are learning Russian.

3. Discussion and conclusions

The present study examined the acoustic correlates of Russian final devoicing. Three participant groups were contrasted: native speakers of Russian with no knowledge of English, native speakers of Russian who are currently living in the US and have extensive knowledge of English, and American English second language learners of Russian. In order to examine word-final neutralization for the speakers' productions, four measures were analyzed: duration of the vowel preceding the final obstruent, duration of the final obstruent (either closure duration for stops or frication duration for fricatives), duration of voicing into closure/frication portion of the final obstruent, and duration of the release portion of the final stop.

Comparison of the results for the separate groups of participants indicates that speakers differentially make use of distinct

acoustic cues in contrasting underlying voiced and voiceless final obstruents. When analyzed as a homogeneous group, native speakers of Russian, including native speakers with and without knowledge of English, produced significant differences between final obstruents, with longer vowel duration, shorter closure/frication duration, longer voicing into closure, and shorter release portion for words ending in underlying voiced obstruents. However, when analyzed separately, speakers of Russian with no knowledge of English preserved the distinction between underlying voiced and voiceless final obstruents through manipulating only the duration of the closure/frication (16 ms difference) and release portion (16 ms difference). In contrast, speakers of Russian with extensive knowledge of English, a language with no final devoicing, showed significant differences in all measures (vowel duration, closure duration, voicing into closure duration, and release portion) between underlying voiced and voiceless final obstruents. For Russians with knowledge of English, the differences observed for closure duration and release portion duration were very similar (15 and 17 ms, respectively) to those produced by monolingual speakers of Russian. However, the differences for vowel and voicing into closure duration increased to 8 and 6 ms (compared to 2 and 1 ms), respectively, showing significant differences between underlying voiced and voiceless final obstruents.

A significant finding from the correlation analysis was that cues for word-final voicing were influenced by speakers' knowledge of second language phonological processes. The influence of L2 on L1 has been documented before. Most notably, in his study of word-initial stops, Flege (1987) showed that the most proficient English learners of French had VOTs that were in between the native English and French norms. The same was true for the most proficient French speakers of English. In the present study, we find that for Russian speakers, knowledge of a second language which lacks final devoicing leads to significant differences in production of their native language. Specifically, vowel duration differences between voiced and voiceless final obstruents increased as the native Russian speakers' English experience (years studying plus years spent in an English-speaking country) increased and this also held if vowel differences were correlated with self-ratings of grammar and pronunciation proficiency.

The correlation analysis clearly shows that Russian speakers with relatively more knowledge of English produced a greater vowel duration difference between underlying voiced and voiceless final obstruents than those with less exposure to English. Differences in vowel duration are important perceptual cues to voicing for speakers of English (e.g., Denes, 1955; Raphael, 1972) and this may account for the enhancement of these vowel differences in the Russian productions of Russian speakers who had exposure to English. Although native speakers of Russian as a group produced a significant difference in vowel duration in the expected direction between underlying voiced and voiceless final obstruents, these data suggest that some of this effect was due to second language interference. Significant exposure to English-a language that lacks final devoicing and uses vowel length extensively to signal the voicing of the following consonant-affected the ability of Russian speakers to produce final devoicing natively and enabled them to realize differences in underlying voicing in terms of differences in vowel duration.

In a recent study, Kondaurova and Francis (2008) showed that English listeners rely much more on vowel duration than Russian listeners in deciding whether a postvocalic stop consonant is voiced or voiceless. Specifically, nonword continua were created by systematically varying the duration of the vowel preceding a bilabial consonant with ambiguous voicing. Two types of nonwords were used, one with CVCCV structure in which the ambiguous bilabial stop was followed by a voiceless velar stop; the other with CVCV structure. For both continua, results showed that Russian listeners hardly used vowel duration at all. Even at the longest vowel duration, the majority of responses remained voiceless. In contrast, the English listeners switched from reporting very few voiced consonants for short vowel durations to overwhelmingly voiced responses for long vowel durations. This is consistent with the extent to which vowel duration varies as a function of the voicing of the following consonant in the two languages.

The present study also investigated the second language acquisition of word-final devoicing by learners of Russian whose native language does not have such a process. While neutralization has been investigated in detail for native speakers, it is not clear if such processes are mastered by L2 learners. In the present study, American English learners' acquisition of Russian final devoicing showed strong effects of incomplete neutralization in the production of Russian contrasts, similar to the native speakers of Russian. For native speakers of English learning Russian, vowel duration, closure/frication duration, and duration of voicing into closure/frication portion were all used to signal the difference in underlying voicing. Interestingly, these differences were more extreme than the ones produced by native Russian speakers as shown by significant interactions between native speakers and L2 learners for vowel duration, closure/frication duration, and voicing into closure duration. Release portion duration was not involved, which agrees with the fact that final stops in American English are often unreleased and hence cannot serve as reliable cues to voicing in final stops. These data show that learners' first language knowledge of English seems to carry over to Russian, resulting in greater acoustic differences between members of word pairs differing underlyingly in final voicing than what is observed in native speakers.

This is in agreement with recent findings from Smith, Hayes-Harb, Bruss, and Harker (2009) who also investigated the effect of L1 phonology on the second language (examining an L1 with final devoicing and an L2 without, the opposite direction). Specifically, Smith et al. (2009) examined the degree of final devoicing in the German and English produced by German learners of English. Thirteen native German speakers who had lived in the US ranging from 9 months to 17 years ($M=3.8$ years) participated. The 6 primary minimal target pairs were specifically selected such that they were phonologically and/or orthographically similar in both languages. Acoustic analysis showed that the German speakers produced a larger distinction between minimal pairs in English than in German. However, while the German speakers did produce a distinction between English minimal pairs, this distinction was generally smaller than that produced by native speakers of English. Specifically, while there was no difference between the two groups in terms of the degree of vowel lengthening before voiced stops (English L1: 32 ms; English L2: 41 ms), the German speakers produced a smaller difference in terms of closure duration (English L1: 33 ms; English L2: 11 ms) and voicing during closure (English L1: 29 ms; English L2: 11 ms). However, the German speakers produced a significantly greater difference in terms of release burst duration (English L1: 15 ms; English L2: 32 ms).

This raises the question whether American English learners of Russian show a pattern similar to that for native speakers of Russian in terms of amount of L2 knowledge. That is, does increasing proficiency in Russian result in a smaller difference between underlying voiced and voiceless final obstruents? The present study showed a significant negative correlation between vowel duration and Russian L2 experience, suggesting that American English learners of Russian produced smaller differences between tokens contrasting in underlying voicing of final obstruents as their Russian proficiency increased. This indicates

that the more proficient learners were more successfully suppressing the interference of their native language (English) and better approximating the pronunciation norm characteristic of the phonology of Russian. Interestingly, the correlation coefficient examining the influence of L2 experience was similar for the American English learners of Russian (for Russian) and the native speakers of Russian (for English). These data suggest that American L2 learners performing a reading task in Russian were affected by their English phonology with the same consistency as the Russian native speakers performing a reading task in Russian were affected by the phonology of English.

While the more proficient learners of Russian produced smaller durational differences between the members of word pairs differing underlyingly in final voicing, most interesting was the fact that English speakers with the highest proficiency in Russian surpassed even monolingual Russian speakers in neutralizing the difference in voicing of final obstruents. Unlike Russian speakers, who still maintain the underlying distinction, the English-speaking learners who are the most experienced in Russian completely neutralize all durational differences for the four measured parameters. Taking performance of monolingual Russian speakers as the standard, one can conclude that these English speakers of Russian did not in the end achieve the goal of producing final devoicing in a completely native-like manner since they showed complete neutralization. These highly proficient learners of Russian recognized that in Russian all word-final obstruents must be voiceless and thoroughly mastered this rule; however, they did not acquire the skill of preserving the minute underlying distinctions in closure and release portion duration that the monolingual native Russian speakers have.

A question that remains to be explored in future research is whether the L2 Russian experience influences the American English speakers' realization of the final voicing contrast in their native language. Our expectation, based on the results of this study for the L2 English influence on L1 native Russian productions, is that knowledge of Russian may affect the acoustic correlates of voicing in word-final obstruents in the English production of American English L2 learners, especially for the most proficient Russian speakers. In particular, cues to voicing of final obstruents are expected to be reduced in their productions. The magnitude of the effect may vary for different acoustic cues. We expect proficient speakers of Russian to have substantial reduction in the duration of the vowel preceding the voiced consonant and the duration of the closure of the voiceless consonant itself—both among the major cues for final devoicing in Russian.

One final observation concerns the overall duration of the produced segments by the different speaker groups. Speakers of English, when recording Russian, produced the longest vowels and consonants overall, followed by Russian speakers with knowledge of English. Monolingual speakers of Russian produced the shortest vowels and consonants. While it is not surprising that English speakers spoke slower, since it is a common feature of second language speech (e.g., Bent & Bradlow, 2003), it is not clear why speakers of Russian with knowledge of English were slower than monolingual Russians. It is possible that the rate of speech and hence the duration of the segments may have a language-specific basis, given that Russian speakers with knowledge of English produced segments intermediate in duration between monolingual speakers of Russian and speakers of English learning Russian. An alternative explanation is that both native speakers of English learning Russian and native speakers of Russian with knowledge of English were recorded in an anechoic chamber at the University of Kansas. Native speakers of Russian without knowledge of English, on the other hand, were recorded in Russia in a quiet room. As such, this group of speakers was recorded in a more natural, less formal environment, which might have put the participants more at ease and may have elicited more natural productions, which possibly includes more rapid speech. Laboratory environments have often been criticized as resulting in more "unnatural" speech, including hyperarticulation as part of the "clear speech" phenomenon, characterized by slower speech rates (e.g., Krause & Braida, 2002; Maniwa, Jongman, & Wade, 2009).

In conclusion, native speakers of Russian, including native speakers with and without knowledge of English, showed significant differences between final obstruents, with longer vowel duration, shorter closure/frication duration, longer voicing into closure, and shorter release portion for words ending in underlying voiced obstruents. The present study revealed that final devoicing in Russian was incomplete even in the productions of monolingual Russian speakers recorded in a more natural non-laboratory environment. However, there were significant differences for Russian native speakers depending on their L2 knowledge. Native speakers of Russian who had exposure to English introduced additional ways of sustaining a difference between final obstruents contrasting in underlying voicing. They maintained a difference through vowel duration and duration of voicing into closure, in addition to that of closure duration and release portion duration produced by Russian monolingual speakers. Moreover, speakers with higher English proficiency produced greater differences in vowel duration.

The findings of the present study underscore the need to address second language proficiency when examining acoustic properties. Many of the studies investigating incomplete neutralization for a variety of languages were conducted in the United States. The speakers recorded almost inevitably had some amount of exposure to American English and some degree of proficiency in English. As the present study shows, evidence of incomplete neutralization in final devoicing increases when speakers with significant exposure to English are investigated.

An additional contribution of the present study is the inclusion of L2 learners. Second language learners exploit the same set of cues as native Russian speakers do. Native speakers of English learning Russian, true to the phonology of their native language English, kept final obstruents contrasting in underlying voicing well apart via vowel duration, closure/frication duration, and voicing into closure/frication duration, with durational differences for the L2 learners more exaggerated than those produced by native speakers of Russian. And as the learners' experience in Russian increased, the differences in vowel, closure/frication, and voicing into closure/frication duration decreased to such an extent that the most experienced L2 learners were closer to complete neutralization than monolingual speakers of Russian.

The results of this study show that L2 knowledge presents a significant influence in the use of different acoustic correlates of consonant voicing in distinguishing underlying voiced and voiceless final obstruents. Both the native Russian speakers with knowledge of English and the native American English speakers who are proficient in Russian show an interaction of first and second languages. Knowledge of English results in Russian native speakers producing greater durational differences between underlying voiced and voiceless final obstruents, while increased proficiency in Russian is accompanied by the production of smaller differences for English native speakers.

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