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Distinguishing word-final devoicing from utterance-final devoicing: The case of Russian

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Distinguishing word-final devoicing from utterance-final devoicing: The case of Russian

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Abstract

Word-final devoicing is a common phonological process in many languages, including Russian. A number of previous studies have shown that word-final devoicing is incomplete in Russian and other languages. However, most of these studies focused on word-final devoicing in utterance-final position, and thus it is not clear whether incomplete neutralization occurs in word-final position in general, or only in utterance-final position. To address this question, the current study examines word-final devoicing in *utterance-medial* position to tease apart word-final devoicing and utterance-final devoicing. Our new findings include: (i) neutralization is still incomplete in utterance-medial position; (ii) stops and fricatives differ in terms of implementation of devoicing; (iii) phonetic details of incomplete neutralization may be sensitive to prosodic positions.

1. Introduction

1.1 General introduction

Many languages have phonological, laryngeal contrasts. However, exactly how larynx is used to create laryngeal contrasts is still to be fully understood [Ladefoged and Maddieson, 1996: 49]; also important is how laryngeal-based contrasts manifest themselves acoustically in different positions. The present study examines how a word-final—apparently "neutralized"—voicing contrast is implemented in utterance-medial position through a case study of Russian. The current study is situated within the studies of so-called "incomplete neutralization". Russian has a two-way voicing contrast (voiced vs. voiceless) in stops and fricatives. Previous phonological accounts have assumed that Russian voiced obstruents are fully devoiced in word-final positions, resulting in complete neutralization of the voicing contrast [e.g., Halle, 1959; Hamilton, 1980]; that is, underlyingly voiced obstruents become identical to underlyingly voiceless obstruents by way of a phonological process, and hence their phonetic realizations are identical. However, later careful instrumental studies have shown that the Russian devoicing may be phonetically incomplete: small but consistent acoustic differences, which are demonstrably perceptible [e.g., Kharlamov, 2012, 2015], have been observed between "neutralized" obstruents in Russian [among others, Dmitrieva et al., 2010; Kharlamov, 2012, 2014; Kulikov, 2012]. This finding—that devoicing may not be complete—is actually reported in many other languages as well [Port and O'Dell, 1985; Roettger et al., 2011, 2014 for German; Dinnsen and Charles-Luce, 1984 for Catalan; Warner et al., 2004 for Dutch].

Indeed, an increasing number of acoustic and perceptual studies have documented the incomplete neutralization of word-final devoicing in Russian and other languages. However, most of these studies examined word-final devoicing in utterance-final position, thereby conflating "word-final" devoicing and "utterance-final" devoicing. In other words, it is still not clear whether incomplete neutralization occurs in word-final position in general, or incomplete neutralization occurs only in word-final and utterance-final position; i.e. word-final devoicing in utterance-medial position is understudied. As will be discussed in the following section 1.4, utterance-final position may not be the ideal position to explore the nature of (incomplete) phonological word-final devoicing.

The present paper has two aims. One is to fill the above-mentioned descriptive gap by examining word-final devoicing in utterance-medial positions, which will advance our understanding of the nature of word-final devoicing and incomplete neutralization in general. Another is to examine word-final devoicing both in stops and fricatives, which enables us to address the question of whether stops and fricatives differ in terms of (in)complete neutralization. In addition, the current experiment attempts to minimize the effects of lexical factors and orthographic influence to the extent possible.

In the following sections, we will first review the previous studies of word-final devoicing and incomplete neutralization in general (section 1.2) and of Russian word-final devoicing in particular (section 1.3). The specific questions to be addressed in the present study are stated in section 1.4. Section 2 presents an acoustic analysis of word-final devoicing in utterance-medial position. Section 3 discusses the results of the acoustic analysis. Finally, section 4 concludes the paper. Throughout this paper, following the standard tradition, slashes (/ /) are used to indicate underlying representations, while square brackets ([ ]) are used to indicate phonetic representations.

1.2 Word-final devoicing and incomplete neutralization

Word-final devoicing (henceforth, final devoicing) is a common phonological process, both synchronically and diachronically [Blevins, 2006; Myers, 2012]. In many languages, such as Catalan, Dutch, German, and Russian, voiced obstruents devoice in domain-final position [see Myers, 2012 for an extensive cross-linguistic overview]. In languages with final devoicing, it has been traditionally formalized, especially within the generative phonology tradition, that the distinction between voiced and voiceless obstruents is completely lost in domain-final position by way of a phonological rule. In this view, minimal-pairs such as /luk/ and /lug/ should result in complete homophones, [luk] [e.g., Akishina and Baranovskaja, 2010; Cubberley, 2002; Halle, 1959; Hamilton, 1980; Wade 2010]. Final devoicing has also been used as an example for positional neutralization in well-known introductory phonology textbooks [Kenstowicz, 1994; Odden, 2005]. These textbooks assume that minimal-pairs such as /luk/ and /lug/ result in complete homophones.

However, a number of experimental studies have found that neutralization may not be complete, contrary to the assumption held by these formal theories; this is to say, for example, that [luk] derived from /luk/ is phonetically slightly different from [luk] derived from /lug/. Throughout this paper, we use the term "incomplete (neutralization)" if there is an observable acoustic difference between segments that are claimed to be neutralized.

While there is now a large number of studies which demonstrate that some neutralization patterns can be incomplete, some researchers have argued that incomplete neutralization is nothing more than an experimental artifact, such as orthographic influence [e.g., Fourakis and Iverson, 1984]. Therefore, it is important to control for as many confounding factors as possible, in order to establish the existence of incomplete neutralization in Russian and other languages. This task is especially important because incomplete neutralization is not predicted by the standard theories of phonology: if a contrast is neutralized in phonology, the outputs of phonology, or the inputs to phonetics, should be identical. Therefore, phonetics should not treat that neutralized pair of sounds differently. See Port and Leary [2005] for extensive discussion on the problems that incomplete neutralization presents to formal phonological theories. (This is not to say, however, that incomplete neutralization is impossible to deal with in formal phonological theories. See Braver [2013] for a review of various approaches to incomplete neutralization within formal phonological theories.)

A classic study of incomplete neutralization is on German final devoicing [Port and O'Dell, 1985]. Port and O'Dell [1985] examined German final devoicing using 10 minimal pairs of words produced in isolation for stop consonants. Their results showed that there were significant durational differences between the underlyingly voiced stops and the underlyingly voiceless stops. For example, the vowels preceding an underlyingly voiced stop (e.g., *Rad* [ʁa ːt] 'wheel') were on average 15 ms longer than those preceding an underlyingly voiceless stop (e.g., *Rat* [ʁaːt] 'council'). Further, those differences were perceptible to native German listeners, although the accuracy rate was only slightly above the chance-level. Based on these findings, Port and O'Dell [1985] concluded that neutralization was incomplete. Similar patterns of incomplete neutralization have since been identified in many languages, in which small but consistent phonetic differences have been observed between segments that are assumed to be completely neutralized [among others, Charles-Luse, 1985; Piroth and Janker, 2004; Port and O'Dell, 1985; Port and Crawford, 1989; Roettger et al., 2011, 2014, for German final devoicing; Dinnsen and Charles-Luce, 1984, for Catalan final devoicing; Ernestus and Baayen, 2006, 2007, Warner et al., 2004, for Dutch final devoicing; Dmitrieva et al., 2010, Kharlamov, 2012, 2014, Kulikov, 2012, for Russian final devoicing; Braver 2013, Herd et al., 2010, for American English flapping; Fourakis and Port, 1986, for American English stop epenthesis; Yu, 2007, for Cantonese tonal merger].

There has now thus been a large body of work claiming the existence of incomplete neutralization. However, a number of phonetic experiments have also found that our speech production patterns can be influenced by multiple factors, which may raise the question of whether the previous findings on incomplete neutralization could be an experimental artifact. For example, the extent to which some contrasts are incompletely neutralized has been shown to be task-dependent, including the presence/absence of orthographic stimuli [Fourakis and Iverson, 1984; Kharlamov, 2012, 2014; Warner et al., 2006]. Fourakis and Iverson [1984] examined the influence of orthographic stimuli on the acoustic realization of final obstruent devoicing in German. Their results showed that, when the speakers were presented with orthographic stimuli (i.e., a traditional reading task), there was clear evidence for incomplete neutralization. In contrast, no clear evidence for incomplete neutralization was found when the speakers were asked to conjugate verbs without orthographic stimuli (a verbal conjugation task). On the basis of their results, Fourakis and Iverson [1984] concluded that the apparent case of incomplete neutralization found by Port and O'Dell [1985] was merely due to the effect of the German orthography.

Despite the concern raised by Fourakis and Iverson [1984], recent studies suggest that the phonetic differences in a neutralizing position cannot be exclusively attributed to the orthographic influence. In their study on German final devoicing, Roettger et al. [2011, see also 2014] adopted an experimental task in which nonce words were elicited by presenting the stimuli to the speakers with auditory cues, thereby minimizing the effects of orthography. The results showed that significant differences were observed in terms of preceding vowel duration and burst intensity. They concluded that, contrary to Fourakis and Iverson [1984], incomplete neutralization does occur even when the speakers are not exposed to orthographic differences. The orthographic effects on final devoicing have been examined in other studies on incomplete neutralization as well [Ernestus and Baayen, 2006; Kharlamov, 2012; Warner et al., 2004, 2006], and these studies showed that, in general, acoustic differences are greater when the speakers are presented with orthographic cues than when they are not, but that nevertheless, incomplete neutralization is observed even without the presence of orthographic input.

In addition to the effect of orthography, word-specific factors such as lexical frequency [Pierrehumbert, 2002; VanDam and Port, 2005], and the presence/absence of a lexical neighbor [Baese-Berk and Goldrick, 2009; Wright, 2004] are shown to affect phonetic realizations, potentially resulting in apparent cases of incomplete neutralization. For example, VanDam and Port [2005] showed that the VOT of English /t/ is longer in low lexical frequency words than in high frequency words. Baese-Berk and Goldrick [2009] found that the presence/absence of minimal pairs among lexical items can affect the duration of VOT in English. They showed that the VOT of a word-initial /p/ was significantly longer when the word in question has a minimally contrasting neighbor (e.g., *pox* [p^{h}ɔks] has an existing minimal pair, *box* [bɔks]) than when it does not have such a neighbor (e.g., *posh* [pʰɔʃ] vs. **bosh* [bɔʃ]).

These lexical effects on phonetic implementation should be taken into consideration in the study of incomplete neutralization. For example, suppose that in studying a case of incomplete neutralization, we may find that the burst of [t] of the underlying /t/ is longer than that of underlying /d/; however, that longer burst may be due to the fact that the words containing /t/ happen to be less frequent or have a minimal pair (i.e., hyperarticulated due to lexical reasons). Similarly, suppose that words containing /d/ were hyperaticulated due to some lexical factor. This would result in longer preceding vowel duration, which may look like incomplete neutralization. We thus feel it necessary to show that incomplete neutralization occurs independent of such lexical frequency effects. At the very least, in studying incomplete neutralization, it would be ideal to minimize the effects of lexical factors and orthographic influences, to the extent possible.

1.3 Background on Russian word-final devoicing

Russian is one of the many languages in which the distinction between underlyingly voiced and voiceless obstruents is thought to be neutralized in word-final position [e.g., Akishina and Baranovskaja, 2010; Cubberley, 2002; Hamilton, 1980; Halle, 1959; Wade, 2010]. The domain of final devoicing in Russian is considered to be a prosodic word, which includes prepositions and lexical content words [Padgett, 2012]. At the right edge of a prosodic word, underlyingly voiced and voiceless obstruents are, impressionistically speaking, homophonous (e.g., [luk] from /luk/ ‘onion$_{\text{.MASC.NOM.SG.}}$’ vs. [luk] from /luɡ/ ‘meadow$_{\text{.MASC.NOM.SG.}}$’). However, the actual status of this neutralization has long been debated.

Previous instrumental studies have observed small acoustic differences between these neutralized "homophones" [Chen, 1970; Dmitrieva et al., 2010; Kharlamov, 2012, 2014; Kulikov, 2012; Pye, 1986; Shrager, 2012]. Using a word-reading task, Dmitrieva et al. [2010] showed that there are significant acoustic differences between underlyingly voiced obstruents and underlyingly voiceless obstruents in word-final position, when the speakers read the words in isolation. For monolingual speakers of Russian, constriction duration was significantly longer for underlyingly voiceless obstruents than for underlyingly voiced obstruents. They also found that the duration of the release burst of the underlyingly voiceless stop was significantly longer than that of the underlyingly voiced stops. Shrager [2012] examined dental stops in utterance-final position, and reported results that are similar to those of Dmitrieva et al. [2010]. Chen [1970] and Kulikov [2012] reported that vowels preceding underlyingly voiced stops were longer than those preceding underlyingly voiceless stops. Kulikov [2012] also found that the first formant (F1) was lower before underlyingly voiced stops than before underlyingly voiceless stops. The results of these studies suggest that neutralization may be incomplete in Russian word-final position. However, the existence of incomplete neutralization in Russian can and should be more firmly established, because several factors that might affect phonetic details, discussed in section 1.2, were not thoroughly controlled for in those studies. Since most of the previous reading tasks involve Russian orthography, the "incomplete neutralization" found in those studies may have arisen due to the effect of orthography. Other studies have not controlled factors such as the lexical frequencies of the stimuli, which can lead to an apparent case of incomplete neutralization.

In his extensive study of methodological influence on final devoicing in Russian, Kharlamov [2012, 2014] found significant differences in closure duration and burst duration of stops, and frication duration of fricatives between underlyingly voiceless and voiced obstruents. Kharlamov [2012, 2014] examined Russian final devoicing with two tasks: a reading task and a picture-naming/fill-in-blank task, in which speakers were asked to produce existing Russian words in isolation. Since the latter task involved no orthographic stimuli, the observed differences cannot readily be attributed to orthographic effects. Moreover, regardless of whether or not the speakers were exposed to both members of lexical minimal pairs in the stimuli, neutralization was incomplete. In summary, Kharlamov [2012, 2014], arguably the best controlled experiment on Russian incomplete neutralization, found that the observed acoustic differences cannot be relegated away as methodological artifacts. Further, Kharlamov [2012] controlled for the lexical token frequencies of the target words, minimizing the potential effects of lexical factors discussed above. Yet, Kharlamov's [2012, 2014] studies targeted only utterance-final positions, which could be a concern, as further discussed in section 1.4.

To summarize, previous instrumental studies suggest that Russian final devoicing is perhaps incomplete, and that acoustic differences found between supposedly neutralizing obstruents cannot be regarded as the consequence of orthography, the presence or absence of a minimal pair in the lexicon, or lexical token frequency[1]. We nevertheless feel that there are still some gaps to fill.

1.4 The questions and the motivations of this study

While previous studies extensively documented Russian final devoicing in utterance-final position [e.g., Khalramov, 2012, 2014], word-final devoicing in *utterance-medial* position is understudied. The only study that we are aware of is Kulikov [2012], who

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[1] While the focus of the present study is acoustic aspects of word-final devoicing, there are a few studies on the perception and aerodynamics of incomplete neutralization in Russian [Kanibolotskaja, 2009; Kharlamov, 2012, 2015; Matsui, 2011]. Kanibolotskaja [2009] found that the underlyingly voiced and voiceless bilabial stops differ in intraoral air pressure. Matsui [2011] demonstrated that "incompletely" neutralized velar stops were perceptually distinguishable by the native listeners of Russian. Kharlamov [2012, 2015] extended Matsui's [2011] observation with a large data set.

examined final devoicing in utterance-medial position by embedding the target words in a frame sentence. As discussed above, Kulikov's results showed that, for stops, the underlying voicing was distinguished by the preceding vowel duration and F1 before the stop, when the speakers performed a reading task. However, this study has a number of limitations. First, as discussed above, Kulikov [2012] used a reading task, and hence the results may have been due to orthographic influences. Second, since he examined only a small set of minimal pairs of existing words, the results can be attributed to lexical factors. Third, since the focus of Kulikov’s [2012] study was stop consonants, the behavior of fricatives in utterance-medial position has remained unexplored.

There are some reasons to expect that final devoicing can be different in utterance-final position and in utterance-medial position. First, devoicing is phonetically motivated in utterance-final position [e.g., Myers, 2012; Myers and Padgett, 2014; Smith, 1997, 2003], because utterance-final segments often suffer from passive devoicing. In non-speech mode, the vocal folds are separated apart to facilitate breathing; therefore, toward the end of an utterance, speakers tend to start spreading apart their vocal folds, resulting in cessation of vocal fold vibration. In addition to this "coarticulation to the non-speech state", the subglottal air pressure that is necessary to produce vocal fold vibration decreases over the course of an utterance, which also makes the utterance-final segments likely to devoice [see Myers and Padgett, 2014: 400, for a recent summary and the list of references on these; see also Barnes, 2006, for phonetic and phonological characteristics of utterance-final position in general]. Therefore, phonetic, passive utterance-final devoicing is commonly observed in the languages even without phonological devoicing. On the other hand, there is no apparent phonetic motivation for devoicing in utterance-medial position if the word-final obstruent is followed by a vowel or a sonorant [again, see Myers and Padgett, 2014]. In this sense, phonological devoicing in utterance-final position may be confounded by the phonetic utterance-final devoicing; it is therefore important to investigate the behavior of word-final devoicing in non-utterance-final positions, especially when the target consonants are followed by vowels or sonorants.

In addition, since phonetic implementation patterns are significantly affected by differences in prosodic position, studying the difference between word-final position and utterance-final position in terms of final devoicing should be in and of itself interesting. Deciphering the domain of phonological processes has been an issue with continued interests throughout the history of phonological theory [Selkirk, 1980 *et seq*.], and how prosodic structures manifest themselves in terms of acoustics and articulation has also been a topic for intensive investigation [e.g. Byrd et al., 2006; Kuzla and Ernestus, 2011; Wightman et al., 1992]. The current study can be situated as a case study of this tradition as well; while previous studies have revealed how about the phonetic implementation patterns of utterance-final position, what about the word-final position? See section 4 for further discussion on this point.

Another reason to study incomplete neutralization in utterance-medial position is as follows: utterance-final segments are often lengthened, which is known as "final lengthening" [e.g., Klatt 1976, Wightman et al. 1992]. This raises a potential concern for the study of incomplete neutralization: it may be the case that speakers incompletely neutralize only when they have time to do so. For example, speakers may implement the lengthening of the vowel preceding /d/, only when they have time to implement that gesture thanks to extra time provided by utterance-final lengthening. The question that arises is thus whether incomplete neutralization is observed, even without the extra time provided by utterance-final lengthening.

In summary, studying the phonetic implementation pattern of devoiced voiced obstruents in word-final, utterance-medical position is important for several reasons.

Additionally, this study addresses another topic that has not been sufficiently addressed in the previous research: the difference between stops and fricatives. Stops and fricatives might differ in how they devoice, since voicing in stops and fricatives face different kinds of aerodynamic challenges [e.g., Davidson, 2016; Ohala, 1983; Solé, 2002; Żygis et al., 2012]. In stops, maintaining voicing duration during closure is challenging, because the rise in intraoral air pressure, which results from stop closure, inhibits glottal airflow. Speakers often deal with this problem by expanding their oral cavity, thereby lowering the intraoral air pressure. However, this simple solution does not work for voiced fricatives, because fricatives require high glottal airflow to create supralaryngeal frication, which in turn makes it difficult to keep intraoral air pressure sufficiently high [Ohala, 1983; Solé, 2002]. Therefore, voicing in fricatives requires more delicate articulatory maneuvers, compared with voicing in stops. Despite this difference, previous studies on incomplete neutralization usually focused on stops [e.g., Kulikov, 2012 for Russian; Roettger et al., 2011, 2014 for German; Warner et al., 2004 for Dutch], and a direct comparison between stops and fricatives is rarely done. As mentioned in section 1.3, Dmitrieva et al. [2010] and Kharlamov [2012, 2014] tested both stops and fricatives in utterance-final position. Again, since utterance-final position is not an ideal condition to look at phonological final devoicing, it still remains unclear whether stops differ in fricatives in terms of final devoicing. Thus, it would be of interest to investigate how stops and fricatives may (or may not) differ in terms of how they devoice incompletely.

To summarize, the present study examines incomplete word-final devoicing from a few new perspectives through a case study of Russian word-final devoicing in utterance-medial position both for stops and fricatives. The specific questions to be addressed in this study are: (i) will we observe incomplete neutralization in utterance-medial position? and (ii) do stops and fricatives behave the same way in terms of phonological devoicing? To this end, we adopt the experimental paradigm used in Roettger et al. [2011, 2014] for German final devoicing to examine Russian word-final devoicing in utterance-medial position.

Throughout this paper, phonemic representations follow the latest IPA illustrations of Russian [Yanushevskaya and Bunčić, 2015]. For the sake of typographical simplicity, we use [t] and [d] to represent dental stops without the diacritic.

2. Methods

2.1 Participants

Twelve native speakers of Russian, aged 19-22 (Mean age: 20.8, SD: 0.9), participated in the production experiment. Seven were female and five, male. All of the participants were born and raised around the city of Orenburg in Russia. The kind of Russian spoken in this region is reportedly not different from Standard Russian ("*literaturnyj Russkij jazyk*") in terms of voicing contrast and final devoicing [Avanesov and Orlova, 1965: 84]. None of the participants reported that they use other languages on a daily basis. Two of the participants reported that their national background is both Russian and Kazakh, although they reiterated that they could only speak Russian. All participants were thus monolingual speakers of Russian.

2.2 Speech materials

All the non-palatalized obstruents that have a voicing contrast in Russian were examined: bilabial (/p/, /b/), dental (/t/, /d/), and velar (/k/, /g/) stops and labiodental (/f/, /v/), alveolar (/s/, /z/) and post-alveolar (/ʃ/, /ʒ/.) fricatives. The vowels preceding the target obstruents were /i/, /e/, /a/, /o/ or /u/. 30 minimal pairs (6 consonant types × 5 vowels) were used as the stimuli. The stimuli were all nonce nouns. The current study used nonce words in order to minimize the word-specific phonetic effects, such as lexical frequency effects or the effect of the existence of a minimal pair as reviewed in section 1. All of the stimulus items were monosyllabic words, consisting of either CVC or CCVC structures. The list of all the target words appears in the appendix. In addition to the target words, 60 fillers were added.

In order to elicit these target items without orthography, we used auditory prompts. The auditory prompts were produced by a native speaker of Russian (a female speaker in her twenties from Orenburg). As described in the next section, the stem-final obstruents used in these auditory prompts were followed by a vowel; hence the voicing contrast was not neutralized. The acoustic properties of the auditory prompts are provided in Table 1. The directions of these patterns between voiceless and voiced obstruents are consistent with those that are reported cross-linguistically [Kingston and Diehl, 1994, among others]: Preceding vowels are longer before voiced obstruents, closure voicing is longer during voiced obstruents, constriction durations are shorter during voiced obstruents, release bursts are longer for voiceless obstruents, and F0 and F1 are generally higher preceding voiceless obstruents.

Table 1. Summary of the acoustic properties of the auditory prompts (a female speaker, *non*-neutralizing position). The first four parameters are all duration. See section 2.4. below for details.

Stops	Bilabial		Dental		Velar	
	Voiceless	Voiced	Voiceless	Voiced	Voiceless	Voiced
	/p/	/b/	/t/	/d/	/k/	/g/
Vowel	114	123	110	124	117	131
[ms]	(7)	(17)	(30)	(18)	(15)	(16)
Voicing	16	71	12	61	12	58
[ms]	(4)	(14)	(6)	(5)	(3)	(5)
Constriction	92	71	97	61	80	58
[ms]	(15)	(14)	(5)	(5)	(10)	(5)
Release	14	6	16	7	25	12
[ms]	(3)	(2)	(3)	(2)	(4)	(4)
F0 pre C	196	197	195	193	190	187
[Hz]	(5)	(12)	(6)	(8)	(4)	(3)
F1 pre C	461	474	473	491	462	415
[Hz]	(94)	(88)	(177)	(124)	(105)	(67)
Fricatives	Labiodental		Alveolar		Post alveolar	
	Voiceless	Voiced	Voiceless	Voiced	Voiceless	Voiced
	/f/	/v/	/s/	/z/	/ʃ/	/ʒ/
Vowel	120	138	121	138	123	174
[ms]	(18)	(13)	(25)	(20)	(10)	(27)
Voicing	12	53	10	73	17	64
[ms]	(2)	(8)	(4)	(14)	(6)	(7)
Constriction	120	53	137	80	142	64
[ms]	(13)	(8)	(13)	(12)	(15)	(7)
F0 pre C	194	193	193	185	197	191
[Hz]	(8)	(9)	(4)	(6)	(7)	(6)
F1 pre C	528	471	427	406	497	418
[Hz]	(169)	(92)	(74)	(55)	(211)	(47)

2.3 Procedures

The elicitation method followed that of Roettger et al. [2011, 2014]. Within each trial, one auditory stimulus was first presented to the participants via headphones (SONY MDR-Z700). The auditory stimuli were embedded in a sentence such as: /v kafe sʲidʲelʲi pʲatʲ X-ov/

(‘In the café five X$_{\text{-MASC.GEN.PL.}}$ were sitting’, where X is a target). The stimuli were followed by a masculine genitive plural ending /ov/ [əf], and hence the target words in the prompts were placed in a *non*-neutralizing position. A sample auditory stimulus sentence is given in (1). A perception test confirmed that the voicing contrast in the auditory stimuli was very easily perceived by the native listeners of Russian (10 listeners, forced-choice identification task, average *d′*: 4.135, SD: 0.2)[2].

Next, in response to each auditory stimulus, the participants were asked to produce the target word with the frame sentence such as: /odʲin X jel pʲetʃʲenʲje/ (‘One X$_{\text{.MASC.NOM.SG.}}$ was eating a cookie.’). In the frame sentence, the participants were expected to use a nominative singular form, where the target obstruent is located in a neutralizing position, because it is word-final. The word-final obstruent was always followed by a sonorant-onset verb /jel/ [jel] ‘was eating’ [3]. A sample sentence is shown in (2).

(1) Stimulus:
/v kafe sʲidʲelʲi pʲatʲ prʲigov/
‘In the café five prig$_{\text{-MASC.GEN.PL.}}$ were sitting.’ (The target nonce noun: ‘prig’ /prʲig/)

(2) Expected response:
/odʲin prʲig jel pʲetʃʲenʲje/
‘One prig$_{\text{.MASC.NOM.SG.}}$ was eating a cookie.’

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[2] *d′* is a sensitivity measure in Signal Detection Theory [Macmillan and Creelman, 2005]. Higher *d′* indicates higher sensitivity to stimuli, and *d′* = 0 indicates no sensitivity to stimuli (i.e., chance-level accuracy). *d′*-values higher than 4 are near-ceiling; when unbiased, 95% correct responses would result in *d′*-value of 3.96. Those listeners who checked the stimuli did not participate in the current production experiment.

[3] The current experiment does not tease apart phrase-final position from word-final position. Since the target items were followed by a syntactic VP boundary, it may be possible that there was a phonological phrase boundary after the target words as well. See Selkirk [2000] and Truckenbrodt [1995] for overviews of the languages which place a phrase boundary before a syntactic VP boundary (although there is of course no guarantee that a VP boundary coincides with a phrase boundary in Russian). Teasing apart word-final positions from phrase-final positions is an important task for future experiments.

The 60 target items and 60 fillers were presented in a pseudo-random order, separated in four blocks: minimal pairs never appeared within the same block or adjacent blocks. Orders of items within each block were randomized. Stimuli were presented with a computer program created by Praat [Boersma and Weenink, 2010]. Before the experiment, the participants worked through three practice trials with existing words and seven trials with pseudo words. The participants were encouraged to imagine that they would continue a story according to the Russian sentence (i.e., the auditory stimulus) that they heard.

The recordings were conducted in a quiet room in Orenburg State University and the university dormitory. The tokens were recorded onto a portable recorder (SONY PCM-M10) with a stereo microphone (SONY ECM-MS907) using a 44.1 kHz sampling rate at a 16 bit quantization level. The first channel of the stereo recordings was extracted for the acoustic analysis.

2.4 Acoustic analysis

The target words were acoustically analyzed using the Praat speech analysis software [Boersma and Weenink, 2010]. The following temporal and spectral properties, which are associated with a voicing contrast [e.g., Kingston and Diehl, 1994], were measured:

1. Duration of preceding vowel (*Vowel*);
2. Voicing duration during closure/frication (*Voicing*);
3. Constriction (closure or frication) duration (*Constriction*);
4. Release duration of stop consonants (*Release*);
5. F0 at the edge of the preceding vowel *(F0 pre C*);
6. F1 at the edge of the preceding vowel (*F1 pre C*).

The representative waveforms and spectrograms are given in Figure 1 to illustrate the measurement protocol. For *Vowel*, when a nasal, lateral or fricative preceded the vowel, the onset of the vowel was defined as the time point of abrupt change in amplitude of the waveform. Where a trill preceded the target vowel, the vowel onset was defined as the end of a short silence. The offset of the vowel was identified based on an abrupt change in amplitude and the shape of the waveform.

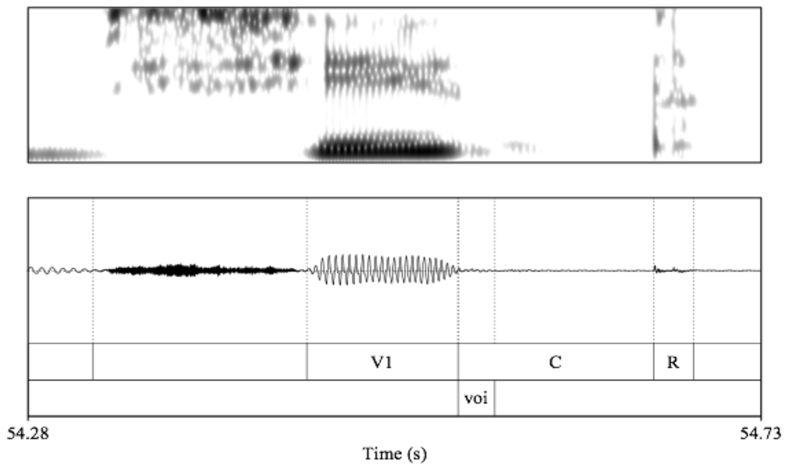


Figure 1. A representative spectrogram and waveform (/z^{j}id/).

Voicing duration during closure/frication was defined as an interval between the offset of the preceding vowel and the end of periodicity in the waveform. The presence of low frequency energy in the spectrogram was also consulted when the end of vocal fold vibration cannot be unambiguously determined based on the waveform. For *Constriction*, closure duration was measured from the vowel offset to the onset of the burst noise. Frication duration was measured from the vowel offset until the end of fricative noise with an abrupt change in the amplitude in the spectrogram. For *Release*, the release duration of stops was measured from the onset of the burst until the end of noise or an abrupt change in the waveform and spectrogram. For *F1 and F0 pre C*, F1 at the offset of the preceding vowel (i.e., the onset of *C*) was extracted by using the Burg algorithm of Praat. F0 was measured using the autocorrelation algorithm.

2.5 The data set

In total, 720 tokens were elicited from the speakers (60 tokens × 12 speakers). 28 tokens (3.8%) were discarded because of pronunciation errors or recording errors. The remaining 692 tokens were submitted for the acoustic analyses.

In the course of acoustic analysis, some tokens were excluded due to the difficulty of unambiguously locating the segmental boundary. The tokens in which the F0 was not correctly extracted due to irregular vocal fold vibration were excluded from the F0 analysis. Two pairs (/ses/-/sez/ and /dnek/-/dneg/) were systematically excluded from the F1 analyses since some participants produced the onset consonant with palatalization, while others without, which can potentially affect F1. The final number of items included for statistical analysis is summarized in Table 2.

Table 2. Number of items submitted to statistical analysis.

Measurement	Stop	Fricative
Vowel	340	352
Voicing	336	352
Constriction	336	352
Release	334	N.A.
F0 pre C	318	332
F1 pre C	318	330

2.6 Statistical analysis

We fit linear mixed-effect regression models for each measurement by using `lme4` package [version 1.1-7, Bates et al., 2014] in *R* 3.1.0 [R Core Team, 2014]. In our models, Underlying Voicing (Uvoi) and Place of Articulation (POA) served as fixed factors, and participants and items as random factors; both a random intercept and slope are included in the model to maximize the model [Barr et al., 2013]. Random slopes for items were not coded for POA, since POA are not random across items in the current design. While Uvoi was dummy-coded (as default setting), POA was sum-coded, so that the intercepts in our model were centered to "devoiced" level averaged across three places of articulation. The default of `lmer` function uses a dummy coding (i.e., treatment contrast), in which one specific level within a factor (e.g., voiceless bilabial stop, but not voiceless stop in general) is set as a reference level (i.e., intercept). However, what we are interested in is the effect of underlying voicing *across* three different places of articulation, not the difference between one specific level (e.g., voiceless bilabial stop) with all other levels. For this reason, we manually sum-coded POA.

In each model, *p*-values are estimated by likelihood-ratio tests. Since separate acoustic dimensions were assessed at the same time, the α-level was adjusted for multiple comparisons by using Bonferroni correction: $\alpha_{\text{adjusted}} = 0.008$ (0.05/6) for stops, $\alpha_{\text{adjusted}} = 0.01$(0.05/5) for fricatives.

2.7 Predictions

As discussed in section 1.4, the specific questions addressed in this study are: (i) when we minimize orthographic and lexical factors, is neutralization still incomplete? (ii) will we observe incomplete neutralization in utterance-medial position? (iii) do stops and fricatives behave the same way in terms of devoicing?

If there is no such thing as incomplete neutralization, beyond experimental artifacts reviewed in section 1, then the prediction is that there should be no differences between underlyingly voiced obstruents and voiceless obstruents, in any of the acoustic dimensions studied here.

On the other hand, as reviewed in section 1.3, Kulikov [2012], who tested the same prosodic environment as the current study, showed that, for stops, the underlying voicing was distinguished by the preceding vowel duration and F1 before the obstruent when the speakers performed a reading task. If the underlyingly voiceless and "devoiced" stops were in fact incompletely neutralized as reported in Kulikov [2012], we would expect a difference in the preceding vowel duration of stops and/or F1 before final stops in the current experiment. If stops and fricatives should behave identically in terms of devoicing, we would observe a difference in the vowel preceding a final fricative and/or F1 before final fricatives, just like final stops.

3. Results

3.1 Stops

The word-final stops in the dataset were typically realized with short vocal fold vibration during stop closure. For the sake of explicit comparison, the distribution of closure voicing (%) is compared between word-final position (Figure 2a) (the experimental targets) and non-word-final position (Figure 2b) (the auditory prompts). In these figures, white bars represent underlyingly voiced tokens, whereas shaded bars represent underlyingly voiceless tokens. The lighter grey bars represent the overlap between the two categories.

As can be seen in Figure 2b, the distributions of underlyingly voiceless and underlyingly voiced stops do not overlap in the non-word-final position, which shows that the voicing contrast was maintained in the auditory prompts. On the other hand, the distributions of underlyingly voiceless and underlyingly voiced stops entirely overlap in word-final position. We take this to be evidence that word-final obstruents were phonologically devoiced, despite being followed by a sonorant. The mean voicing proportion during stop closure was 16% (SD = 12). The representative tokens of word-final stops are illustrated in Figure 3a and 3b.

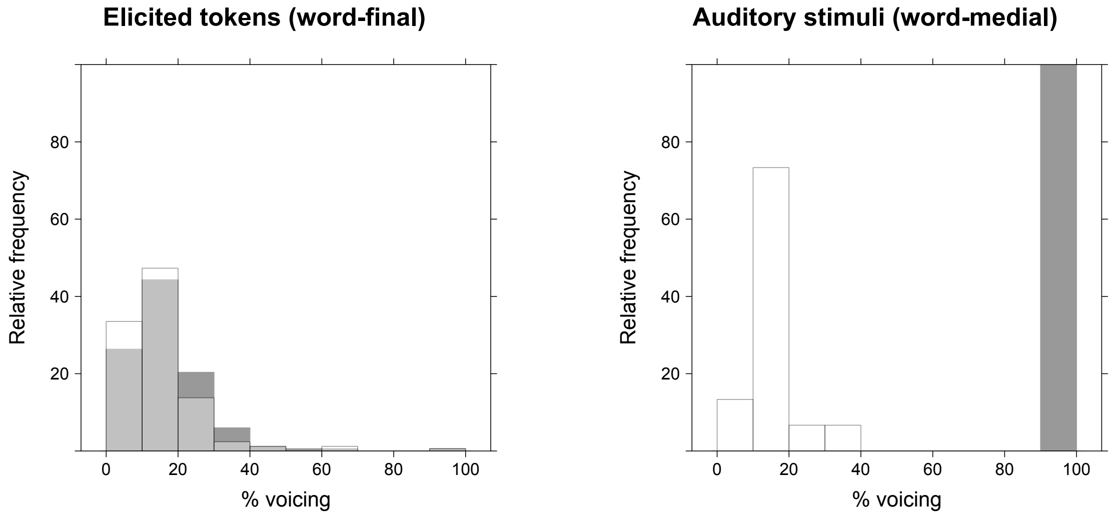


Figure 2a Figure 2b

Figure 2a/2b
The distribution of closure voicing (%) (10 % bin) in word-final position (Figure 2a) and in non-word-final position (Figure 2b). Shaded bars represent underlyingly voiced tokens; white bars represent underlyingly voiceless tokens. The lighter gray represents the overlap between the two categories.

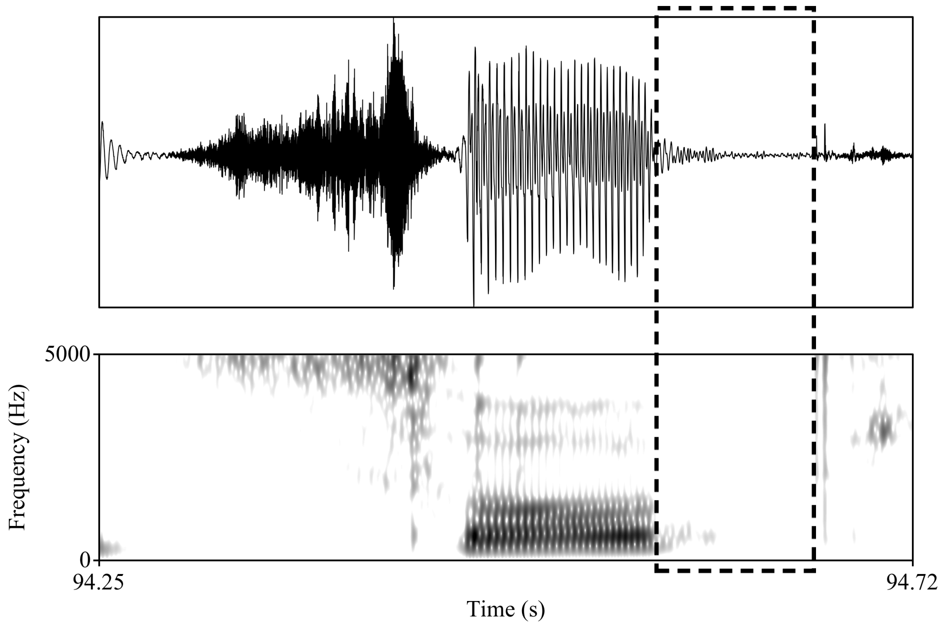


Figure 3a
A representative token of word-final voiceless stops (/tsot/). The closure interval is indicated by a box with a broken line.

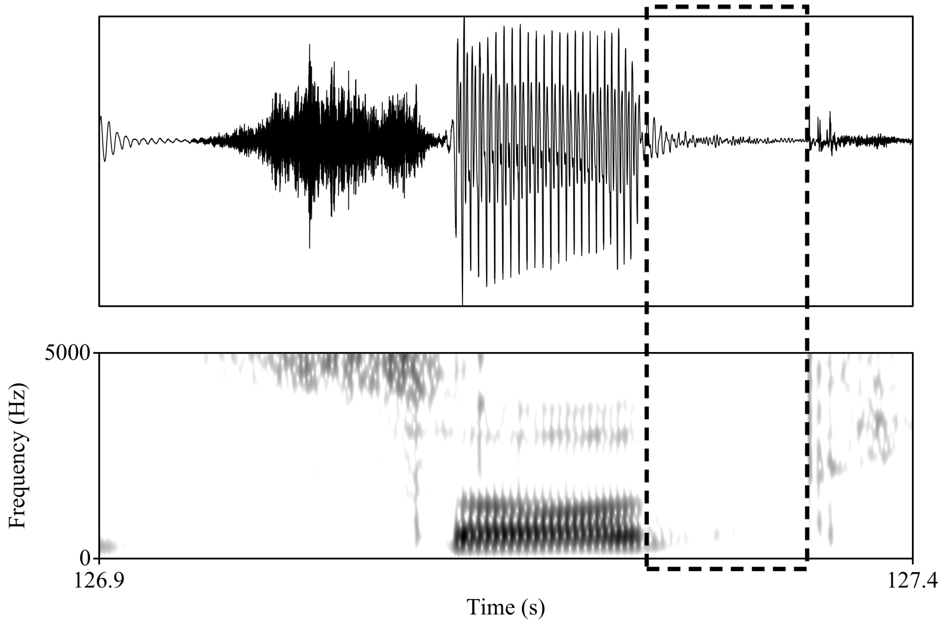


Figure 3b
A representative token of word-final devoiced stops (/tsod/). The closure interval is indicated by a box with a broken line.

Having established that word-final devoicing does take place, Table 3 shows the average acoustic properties of the target comparison, broken down by underlying voicing (voiceless and its "devoiced" counterparts) and place of articulation for each phonetic dimension.

To examine the effect of underlying voicing (Uvoi) on each measurement, we first compared two models: one with the interaction between Uvoi and POA and the other without. Likelihood ratio tests showed that there were no significant interactions between Uvoi and POA for any of the measurements [For *Vowel*, $\chi^2(2) = 1.8024$, $p = 0.4061$; For *Voicing*, $\chi^2(2) = 0.4001$, $p = 0.8187$; For *Constriction*, $\chi^2(2) = 0.3746$, $p = 0.8292$; For *Release*, $\chi^2(2) = 3.4522$, $p = 0.178$; For *F0 pre C*, $\chi^2(2) = 1.8909$, $p = 0.3885$; For *F1 pre C*, $\chi^2(2) = 0.3143$, $p = 0.8546$]. Therefore, we interpreted the simpler model without the interaction term.

Table 3. Average acoustic values with one standard deviation (in parentheses) for measurements (stops). The measurement with statistical significance is indicated in boldface.

	Bilabial		Dental		Velar	
	Voiceless /p/	Devoiced /b/	Voiceless /t/	Devoiced /d/	Voiceless /k/	Devoiced /g/
Vowel **[ms]**	**106 (18)**	**112 (17)**	**106 (25)**	**111 (21)**	**106 (19)**	**115 (23)**
Voicing [ms]	13 (5)	16 (7)	15 (11)	17 (13)	14 (8)	16 (9)
Constriction [ms]	115 (20)	114 (22)	93 (20)	95 (23)	92 (20)	92 (18)
Release [ms]	54 (29)	47 (25)	52 (21)	48 (24)	61 (25)	64 (31)
F0 pre C [Hz]	239 (72)	238 (76)	238 (70)	236 (69)	241 (74)	244 (75)
F1 pre C [Hz]	453 (108)	454 (104)	450 (106)	445 (108)	428 (123)	422 (104)

We found a significant effect of Uvoi in the duration of the preceding vowel [$\chi^2(1) = 10.616$, $p < 0.008$]. As can be seen in Table 3, the vowels preceding “devoiced” stops were longer than those preceding underlyingly voiceless stops. The regression coefficient (β) for Uvoi was -6.5 ms. Since the intercept (i.e., the reference level) in our model was centered to the “devoiced” level across POA, the model shows that the vowels preceding “devoiced” stops are 6.5 ms longer than those preceding voiceless stop. The effect of POA was not significant [$\chi^2(2) = 0.1767$, $p = 0.9154$]. A summary of the model for the preceding vowel duration is shown in Table 4.

For all other measurements (*Voicing, C, Release, F0 pre C and F1 pre C*), the effect of Uvoi did not reach significance. That is, we found evidence for incomplete neutralization, but only in terms of preceding vowel duration for stops.

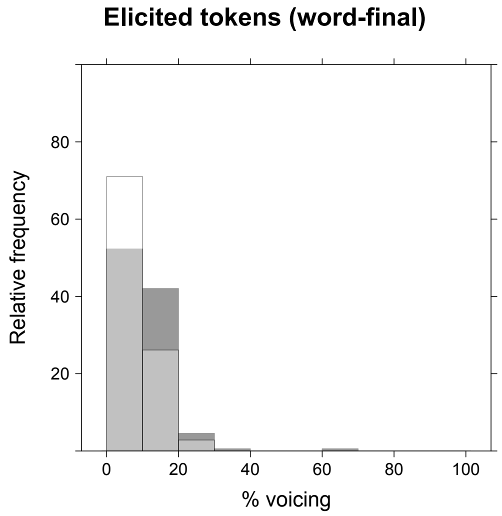
Table 4.
A model summary for preceding vowel duration (for stops). Intercept is centered to "devoiced" level across POA. P values smaller than 0.008 (after being adjusted for multiple comparisons, by Bonferroni correction) are indicated as "*".

Predictor	Estimate (β)	Standard Error	t-value
Intercept ("devoiced")	112.8652	4.0626	27.782
Uvoi (voiceless)	−6.4915	1.6867	−3.849 *
POA (dental)	−0.9177	4.4270	−0.207 n.s.
(velar)	−1.0598	4.3669	−0.243 n.s.

3.2 Fricatives

Similar to stops, the word-final fricatives in the dataset were typically realized with short vocal fold vibration during frication. The distribution of voicing during fricative intervals is compared between word-final position (Figure 4a) and non-word-final position (Figure 4b).

In the neutralizing environment, the two distributions overlap, suggesting that devoicing took place for fricatives word-finally. The mean voicing proportion during frication was 10% (SD = 6). Representative tokens are illustrated in Figures 5a and 5b. Table 4 summarizes the acoustic properties of target words in the neutralization environment.



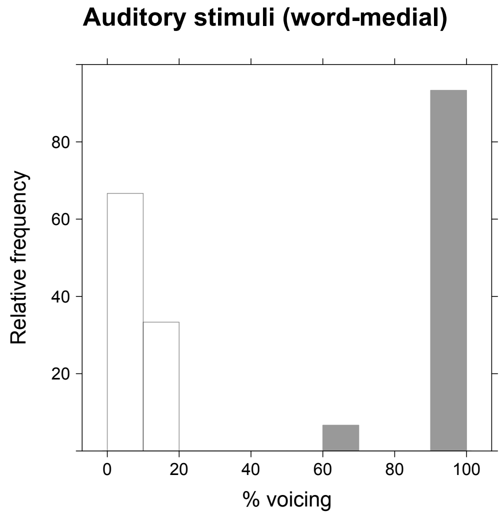


Figure 4a Figure 4b

Figure 4a/4b. The distribution of voiceless and (de-)voiced fricatives along voicing proportion continuum (10 % bin) in word-final position (Figure 4a) and in non-word-final position (Figure 4b). Shaded bars represent underlyingly voiced tokens; white bars represent underlyingly voiceless tokens. The lighter gray represents the overlap between the two categories.

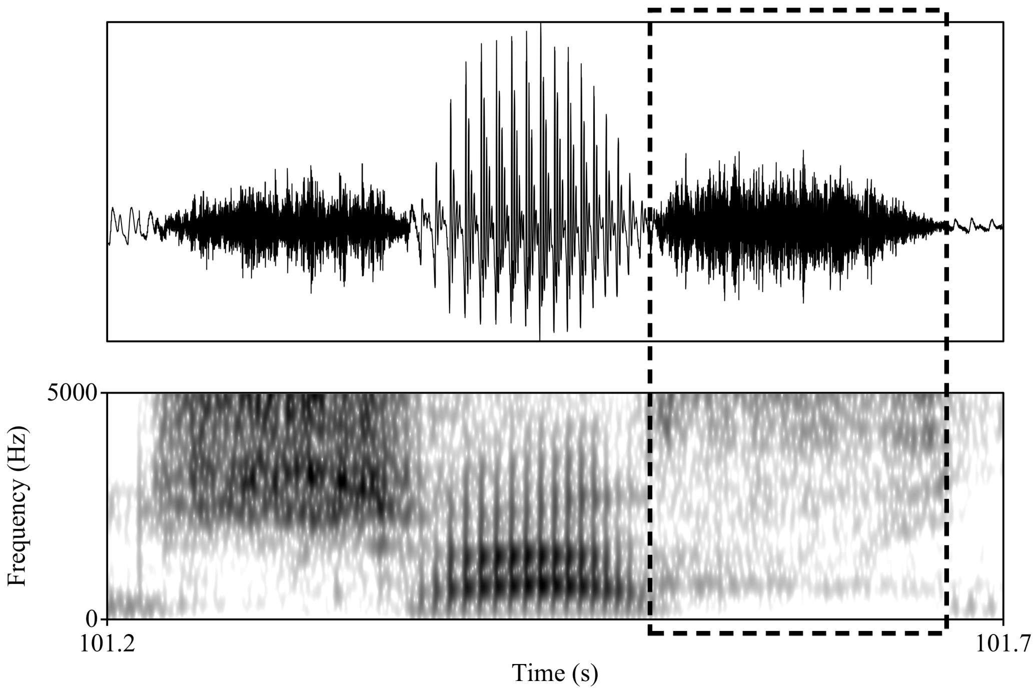


Figure 5a. A representative token of word-final voiceless fricatives (/ʃas/). The frication interval is indicated by a box with a broken line.

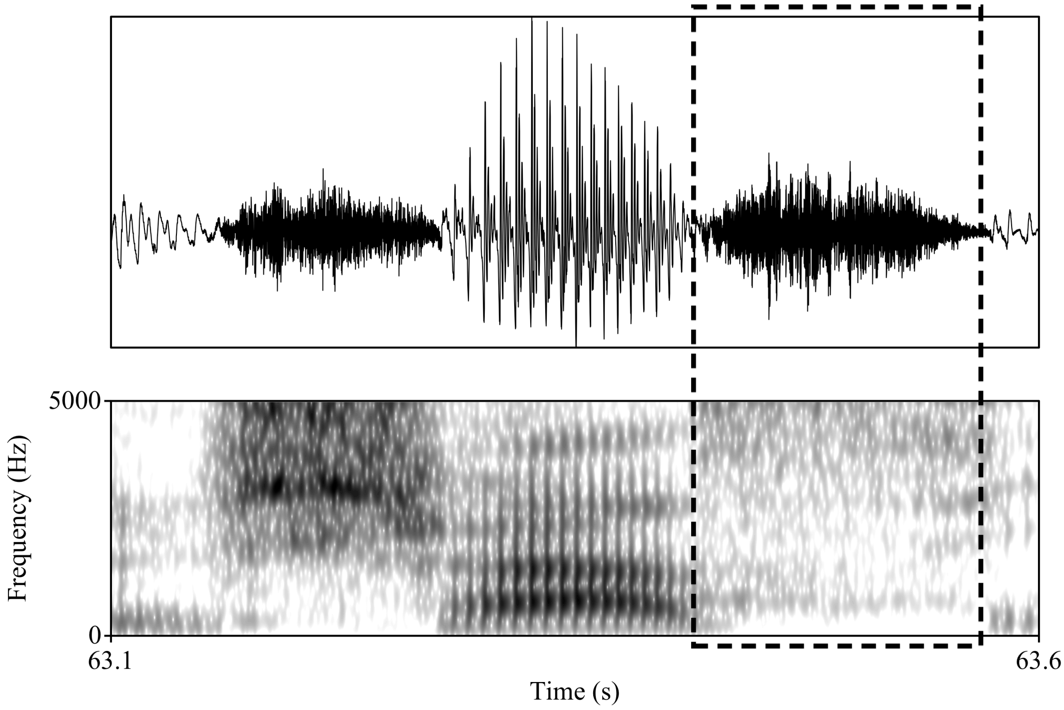


Figure 5b. A representative token of word-final “devoiced” fricatives (/ʃaz/). The frication interval is indicated by a box with a broken line.

Table 5. Average values with standard deviations (in parentheses) for all measurements (fricatives). The measurement with statistical significance is indicated in boldface.

	Labiodental		Alveolar		Post alveolar	
	Voiceless /f/	Devoiced /v/	Voiceless /s/	Devoiced /z/	Voiceless /ʃ/	Devoiced /ʒ/
Vowel [ms]	122 (22)	125 (21)	123 (21)	126 (26)	124 (20)	130 (23)
Voicing **[ms]**	**15 (7)**	**17 (8)**	**11 (6)**	**16 (13)**	**14 (5)**	**16 (7)**
Constriction [ms]	150 (30)	141 (34)	163 (29)	155 (30)	165 (29)	163 (26)
F0 pre C [Hz]	241 (72)	243 (75)	247 (77)	248 (79)	250 (74)	248 (73)
F1 pre C [Hz]	455 (130)	459 (119)	422 (110)	423 (98)	453 (132)	445 (119)

We first compared two models, one with interaction between Uvoi and POA and one without. Again, likelihood ratio tests showed that there were no significant interactions between for any of the measurements [For *Vowel*, $\chi^2(2) = 0.6218$, $p = 0.7328$; For *Voicing*, $\chi^2(2) = 1.8266$, $p = 0.4012$; For *Constriction*, $\chi^2(2) = 1.0244$, $p = 0.5992$; For *F0 pre C*, $\chi^2(2) = 0$, $p = 1$; For *F1 pre C*, $\chi^2(2) = 0.4924$, $p = 0.7818$]. Therefore, we interpret the results with the simpler model without the interaction term.

For the effect of Uvoi in fricatives, we found a weak but significant effect of Uvoi for the duration of voicing during frication [$\chi^2(1) = 5.5843$, $p = 0.01812$]. As observed in Table 5, voicing duration during frication was slightly longer during underlyingly voiced fricative than during underlyingly voiceless one, although the estimated difference was 2.9 ms.

Finally, the effect of POA was not significant [$\chi^2(2)=5.6914$, $p=0.05809$]. A summary of the model for the preceding vowel duration is shown in Table 6. For all other measurements (*V1, C, F0 pre C, F1 pre C*), the effect of Uvoi was not significant.

Table 6. A model summary for voicing duration (for fricatives). Intercept is centered to "devoiced" level across POA. *p*-values smaller than 0.05 but greater than 0.01 (after being adjusted for multiple comparisons, by Bonferroni correction) are indicated with "＊".

Predictor	Estimate (β)	Standard Error	t-value
Intercept ("devoiced")	16.3051	1.3362	12.203
Uvoi (voiceless)	−2.8941	1.1290	−2.563 ＊
POA (labiodental)	−1.5465	0.7633	−2.026 n.s.
(postalveolar)	1.3793	0.6238	2.211 n.s.

4. Discussion

The present study addressed two questions about incomplete neutralization, using an experimental paradigm that minimized the effects of orthography and lexical factors. The first question was whether incomplete neutralization holds in non-utterance-final positions. The second question was whether stops and fricatives differ in terms of devoicing. The summary of our findings and the implications of our results are discussed in the following sections.

4.1 Word-final devoicing in utterance-medial position

Our results show that there are significant acoustic differences between the words containing underlyingly voiced and those containing underlyingly voiceless obstruents. For stops, the duration of the preceding vowel was significantly longer before the underlyingly voiced stop than before preceding the underlyingly voiceless stop. For fricatives, voicing duration was longer in underlyingly voiced fricatives than in underlyingly voiceless fricatives. The results in general confirm that incomplete neutralization is indeed observed in utterance-medial position, even when speakers produced nonce nouns in response to the auditory stimuli. Incomplete neutralization was observed even when the effects of orthography or word-specific effects are minimized.

The difference we observed in the preceding vowel duration is consistent with the results of Kulikov [2012], who examined final devoicing in stop consonants in utterance-medial position. The direction and the magnitude of the difference observed in the present study is fairly close to that in Kulikov [2012]; our LME regression model estimated 6.5 ms vowel difference as a function of underlying voicing of stop, while the difference observed in Kulikov [2012] was 6 ms.

On the other hand, while Kulikov [2012] observed a difference in F1 before the final obstruent, no such differences were found in the present study. The difference may come from the difference in the experimental tasks: Kulikov examined existing words by using a reading task, while this study used the pronunciation of nonce words in response to auditory stimuli. This in turn suggests that different task formats may influence how incomplete neutralization manifests itself.

Another possibility is a regional difference: Kulikov [2012: 27] recorded his data in Tambov, while our speakers were from Orenburg. However, this explanation is probably unlikely, as those are presumably the same variety of Russian, in that both of them have voicing contrast and final devoicing process [Avanesov and Orlova, 1965:84].

4.2 The difference between stops and fricatives in the implementation of devoicing

As discussed above, for stops, we found the effect of underlying voicing in the vowel preceding stops, *a la* Kulikov [2012]. Our hypothesis for fricatives was, if stops and fricatives behave identically in terms of devoicing, we would observe the same difference. Contrary to this prediction, we found a weak effect of underlying voicing on voicing duration during frication. The results suggest that stops and fricatives show different patterns of incomplete neutralization.

Why do stops and fricatives behave differently raise an important theoretical question; since stops and fricatives behave differently phonetically, do they possibly undergo two different “devoicing rules”? We find this unlikely for the following reason. As reviewed in Padgett [2011], Russian sonorants do not undergo obligatory devoicing, except for gradient, non-obligatory devoicing. In contrast with sonorants, our results (Figure 2a and 4a) showed that both stops and fricatives devoiced almost obligatorily, which is qualitatively different from the case of sonorants. In this sense, stops and fricatives form a natural class, and it is natural to think that the same process targets that class.

It is unlikely that speakers can control 3 ms difference of voicing for fricatives. Given the speech with 167 Hz, 3 ms corresponds to a half of one cycle. Therefore, where this small difference comes from is a very difficult task to address. Recall, however, that our effect sizes are not very different from other studies of incomplete neutralization. Also for stops, it should be noted that why vowels are longer before voiced stops is a matter of extensive debate in the first place [e.g., Kluender et al., 1988 vs. Folwer, 1992]; and therefore, solving this question in the context of incomplete neutralization is even more complex.

Ultimately, our observation that stops and fricatives behave differently may bear on the question of how to model incomplete neutralization. There are various theoretical proposals of incomplete neutralizations, including the one deploying the interactions between phonetic context and surface underspecification [Matsui, 2015], phonetic paradigm uniformity constraints with weighted constraints [Braver, 2013], the difference in exemplar clouds [e.g., Ernestus and Baayen, 2007], or the combination of grammar dynamics and environmental dynamics [Gafos, 2006]. We cannot offer conclusive remarks here, but how each theory of incomplete neutralization can handle the differences between stops and fricatives offers an interesting theoretical challenge.

4.3 The role of prosodic conditionings on final devoicing and incomplete neutralization

To put the current findings into a broader perspective, our results are in line with other previous studies in Russian, which found incomplete neutralization in existing Russian words [Chen, 1970; Dmitrieva et al., 2010; Kharlamov, 2012, 2014; Kulikov 2012]. Table 7 shows a survey of the acoustic studies of word-final devoicing in Russian. As can be seen in Table 7, Kulikov [2012] and the present study show similar results; that is, they both found the effect of underlying voicing on the preceding vowel duration. On the other hand, Dmitrieva et al. [2010] and Kharlamov [2012, 2014] found no significant difference in preceding vowel duration. Instead, they found the difference in closure/frication duration and release duration of stops. This difference may come from the difference in prosodic conditions examined: while Kulikov [2012] and the present study embedded the target words in the middle of a sentence (i.e., utterance-medial position), Dmitrieva et al. [2010] and Kharlamov [2012, 2014] asked the speakers to produce the words in isolation (i.e., utterance-final position). As discussed in section 1.4, since utterance-final position undergoes phonetic lengthening [e.g. Klatt 1976, Wightman et al., 1992], this may have affected the results of Dmitrieva et al. [2010] and Kharlamov [2012, 2014]. These observations suggest that the type of the prosodic boundary after the word-final obstruent may affect the acoustic profile of word-final devoicing. The effects of prosodic boundary on phonetic details have been receiving attention in the recent literature [e.g., Kuzla and Ernestus, 2011]; our study shows that prosodic differences can in fact affect how segmental devoicing is implemented.

In general, prosodic domains define the domains within which phonological rules or constraints apply [Selkirk, 1980 et seq]. They also determine the patterns of phonetic implementation, especially through domain-edge strengthening and final lengthening [Byrd et al., 2006; Wightman et al., 1992]. The present study discovered another aspect in which prosodic domains are important: they may define the way in which a particular contrast is incompletely neutralized.

Table 7. Comparison with previous acoustic studies in Russian in a chronological order. All the studies except Kulikov [2012] and the current study referred to *utterance-final* position.

Study	Obstruent	Task	Acoustic cues	Notes
Chen (1970)	/p, b, t, d, k, g/	Reading	Preceding vowel	1 speaker, No statistical analysis
Pye (1989)	/p, b, t, d, k, g, f, v, s, z, ʃ, ʒ/	Reading	Preceding vowel; Voicing; Constriction; Release	No statistical analysis
Shrager (2010)	/t, d/	Reading	Constriction; Release	
Dmitrieva et al. (2010)	/p, b, t, d, k, g, f, v, s, z, ʃ, ʒ/	Reading	Constriction; Release	Both for monolingual and bilingual speakers; Lexical factors controlled; Real words
Kulikov (2012)	/p, b, t, d, k, g/	Reading	Preceding vowel; F1 pre C	
Kharlamov (2012, 2014)	/p, b, t, d, k, g, f, v, s, z, ʃ, ʒ/	Reading; Non-reading	Constriction; Release	Lexical factors controlled; Real words
Current study	/p, b, t, d, k, g, f, v, s, z, ʃ, ʒ/	Non-reading	Preceding vowel (stops); Voicing (fricatives)	Lexical factors controlled; Nonce words

5. Conclusions

The present study offers additional data regarding the acoustic manifestation of Russian word-final voiceless and voiced obstruents. The results show small but significant durational differences between words with underlyingly voiceless obstruents and the devoiced counterparts, thus illustrating a case of incomplete neutralization. The current results offer non-trivial findings about our current understanding of incomplete neutralization. First, incomplete neutralization arises, even when orthography and word-specific effects are minimized. Second, final devoicing can be incomplete, despite the fact that the target consonants in question are in utterance-medial position, where word-final devoicing is not confounded with utterance-final devoicing. Third, stops and fricatives can behave differently in terms of how they incompletely neutralize voicing contrast. Viewed from a broader perspective, the current study shows that prosodic structures can affect phonetic implementation patterns by determining how incompletely neutralized contrasts manifest themselves.

Acknowledgements

To be added.

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Appendix: Speech Materials (shown in phonemic representation, nonce nouns by definition)

Stops

Bilabial		Dental		Velar	
Voiceless	Voiced	Voiceless	Voiced	Voiceless	Voiced
/rʲip/	/rʲib/	/zʲit/	/zʲid/	/prʲik/	/prʲig/
/lep/	/leb/	/ʒet/	/ʒed/	/dnek/	/dneg/
/tʃap/	/tʃab/	/xrat/	/xrad/	/tsak/	/tsag/
/nop/	/nob/	/tsot/	/tsod/	/zok/	/zog/
/mup/	/mub/	/ʃtut/	/ʃtud/	/bruk/	/brug/

Fricatives

Labiodental		Alveolar		Post alveolar	
Voiceless	Voiced	Voiceless	Voiced	Voiceless	Voiced
/krʲif/	/krʲiv/	/zʲis/	/zʲiz/	/prʲiʃ/	/prʲiʒ/
/tsef/	/tsev/	/ses/	/sez/	/neʃ/	/neʒ/
/naf/	/nav/	/ʃas/	/ʃaz/	/plaʃ/	/plaʒ/
/ʒof/	/ʒov/	/dros/	/droz/	/moʃ/	/moʒ/
/ruf/	/ruv/	/plus/	/pluz/	/luʃ/	/luʒ/