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*Voicing contrast in consonant clusters: evidence against sonorant transparency to voice assimilation in Russian**

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Obstruents in Russian have been claimed to assimilate in voicing in clusters when a sonorant consonant intervenes, e.g. *ot mgly* [dmg] 'from the haze'. This phenomenon ('sonorant transparency to voice assimilation') is controversial: it is claimed to be a phonological rule of fast speech by some linguists, while its existence is denied by others. Previous studies have shown that voicing in presonorant obstruents (C_1) in Russian is consistent with that of prevocalic obstruents in slow speech; however, no research has examined whether voicing in presonorant obstruents changes either as a function of the voicing of the rightmost (C_2) obstruent in a cluster or in faster speech. This paper presents experimental results supporting the claim that the voicing of C_2 obstruents does not affect voicing in presonorant C_1 obstruents in slow or fast speech. The results suggest that obstruents do not assimilate through a sonorant in obstruent–sonorant–obstruent clusters in Russian.

1 Introduction

'Sonorant transparency' in Russian, or voicing assimilation through a sonorant, is one of the most unusual phenomena that have been reported in studies of voice assimilation in the world's languages. It received attention after Jakobson (1978) reported that in his speech an obstruent assimilated to a following obstruent at a proclitic boundary when a sonorant consonant intervened (e.g. *iz Mcenska* [smʦ] 'from Mcensk',

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ot mgly [dmg] 'from the haze'). Later, Hayes (1984) argued that this is a phonological rule of fast speech in Russian. However, the phenomenon has always been controversial. It violates one of the most common properties that have been attributed to obstruents: preservation of voicing specification before a sonorant (Trubetzkoy 1969). Moreover, not every linguist agrees about the existence of sonorant transparency in Russian. Comprehensive phonetic and phonological descriptions of Standard Russian (e.g. Halle 1959, Avanesov 1968) and Russian dialects (e.g. Avanesov & Bromlej 1986) have not reported cases of sonorant transparency. It has been argued to be a gradient phenomenon (Cho 1990, Shapiro 1993, Padgett 2002), limited to the environment before devoiced sonorants (Ševoroškin 1971) or even unattested in Standard Russian (Es'kova 1971, Kavitskaja 1999, Robblee & Burton 1997). In spite of these doubts, the claim that voice can assimilate through a sonorant has been used to support important theoretical generalisations (Kiparsky 1985, Steriade 1999), and is adopted in some phonological analyses of Russian (e.g. Petrova 2003, Rubach 2008).

Whether obstruents can or cannot assimilate in voicing before an intervening sonorant is an important question in phonological theory. It is related to the 'action-at-a-distance' principle (Poser 1982). Non-local agreement in certain distinctive features is not uncommon in languages, and is typically realised as harmony. Distant agreement in nasality or place of articulation can affect results of phonological alternations in derived environments (Rose & Walker 2004). Intriguingly, laryngeal harmony in stops (e.g. in Chaha and Zulu) is usually restricted to roots and does not operate across morpheme boundaries to cause phonological alternations in affixes (Rose 2011). Therefore, even in cases of laryngeal harmony, obstruents in prevocalic/presonorant position *do not change* laryngeal specifications.

Obstruent assimilation in voicing through a sonorant has been claimed not to be unique to Russian. Rubach (1996, 1997) argues that sonorant transparency to voice assimilation is a regular process that occurs both word-internally and across a word boundary in Polish. Unlike in Russian, voice assimilation through a sonorant in Polish can be regressive and progressive. However, the acoustic analysis in Strycharczuk (2012) raises questions about whether phonological sonorant transparency exists in Polish. She finds a complex pattern of results, but argues that Polish speakers show a strong tendency to preserve underlying voicing in presonorant obstruents. Therefore, a search for experimental evidence of presence or absence of sonorant transparency in Russian is crucial for our understanding of the nature of phonological assimilation.

Acoustic studies can be useful in testing the validity of phonetic data upon which phonological analyses are based. While acoustic studies of Russian obstruents suggest that little variation exists in initial and intervocalic voiced and voiceless obstruents (Halle 1959, Barry 1988, 1995, Ringen & Kulikov 2012), there has been no instrumental analysis addressing the important question of how voicing is implemented in

Russian obstruents in voiced and voiceless clusters. To verify whether there is voice assimilation in a consonant cluster, it is crucial to establish whether the acoustic parameters of voicing in the leftmost obstruent change as a function of the voicing category of the rightmost obstruent. In this paper, I argue that there is no effect of the rightmost obstruent on the voicing of the leftmost obstruent in obstruent–sonorant–obstruent clusters in Russian, and hence no voice assimilation. In contrast, a strong effect of the rightmost obstruent in obstruent-only clusters is a direct result of voice assimilation.

This paper is organised as follows. In §2, data illustrating cases of voice assimilation in Russian are presented. §3 is a review of previous studies of the phonetics and phonology of voice assimilation in Russian. §4 and §5 describe an experiment in which cases of voice assimilation in obstruent clusters with and without intervening sonorants were examined. The results show no evidence of sonorant transparency in Russian. Obstruents do not assimilate in voicing through a sonorant. §6 discusses and summarises the results.

2 Voicing contrast and voice assimilation in Russian

Russian has a contrast between voiceless unaspirated stops /p t k/ and fully voiced stops /b d g/.[1] The contrast is preserved in a prevocalic/presonorant position (Avanesov 1968), both word-initially (1a) and word-internally (1b).

(1)	a.	tam	[t]	'there'	dam	[d]	'give (FUT 1SG)'
		trava	[t]	'grass'	drova	[d]	'firewood'
	b.	letok	[t]	'bee-entrance'	ledok	[d]	'(thin) ice'
		metla	[t]	'broom'	vedro	[d]	'pail'

Word-internal morpheme boundaries are usually invisible to voicing processes. For example, final obstruents in prefixes preserve underlying voicing when they occur in a prevocalic/presonorant position, as shown in (2).

(2)	pod + opytnyj	[d]	'experimental (ADJ)'
	pod + lunnyj	[d]	'under the moon (ADJ)'

The boundary between a preposition and a content word is also treated as a word-internal morpheme boundary. Prepositions in Russian behave as affixal proclitics, which do not constitute separate prosodic words and are prosodified with the following noun under a prosodic word (see Selkirk 1995 for a detailed analysis of prosodic

[1] This contrast is also present in the palatalised stops /pʲ tʲ kʲ/ and /bʲ dʲ gʲ/. The two contrasts – voicing and palatalisation – do not interact in Russian phonology, and only plain stops are used in the experiment.

constituents).[2] Like the prevocalic obstruents in prefixes in (2), final obstruents in prepositions preserve their underlying voicing before words beginning with vowels or sonorants, as illustrated in (3).

(3) pod uglom [d] 'at an angle'
pod lampoj [d] 'under the lamp'

Russian is usually described as having regressive voice assimilation in obstruent clusters. Two or more obstruents in a cluster are described as having the same specification for voice, which is determined by the rightmost obstruent in a cluster. Thus, both voicing of an underlying voiceless stop and devoicing of an underlying voiced stop are attested, as shown in (4).

(4) svat' + ba [d^{j}b] 'wedding'
led + ka [tk] 'ice (GEN SG DIM)'
svat + at' [t] 'to ask in marriage'
led + ok [d] 'ice (NOM SG DIM)'

Voice assimilation also occurs across a clitic boundary. Final obstruents in prepositions (proclitics) agree in voicing with the root-initial obstruent, as illustrated in (5).

(5) ot goroda [dg] 'from the city'
k zemle [gz] 'to the ground'
ot ugla [t] 'from the corner'
k otcu [k] 'to the father'

To sum up, obstruents before sonorants are generally claimed to retain their underlying laryngeal specifications when a sonorant segment is a vowel or a consonant followed by a vowel. In some cases, however, obstruents in Russian have been reported to change their voicing specifications before sonorant consonants. Jakobson (1978) reports that in his speech, final obstruents in prepositions (e.g. *iz* 'from, out of' or *ot* 'off, from') agree in voicing with the obstruents following the sonorant, as shown in (6), instead of preserving their laryngeal specification in presonorant position.

(6) iz Mcenska [smt͡s] 'from Mcensk'
ot lgun'ji [dlg] 'from the liar'

No assimilation through a sonorant, however, has been reported within a word. For example, an initial voiceless obstruent in Russian names of

[2] According to Selkirk (1995: 450), the major distinction between 'free' clitics and 'affixal' clitics is in the domain of stress. 'Free' clitics are never stressed, while 'affixal' clitics can be stressed within a word. Another option – 'internal' clitics, which are prosodified within the same prosodic word – is ruled out in Russian, because the clitic–word boundary in this case is word-internal. However, it has been shown (e.g. Rubach 2000) that some phonological processes (e.g. palatalisation) produce the same results across a proclitic–word boundary as across a boundary between two content words.

Polish origin, e.g. *Kržyžanovskij, Prževalskij*, is never pronounced as voiced before a sonorant followed by a voiced obstruent. Voice assimilation through a sonorant has never been reported across a word boundary either, cf. (7).

(7)	kadr plox	[drp]	'the frame is bad'
	sv'okr bolen	[krb]	'the father-in-law is sick'

Cases of sonorant transparency to voice assimilation in Russian have thus been claimed to be found in a single restricted environment: in clusters across a prepositional boundary.

3 Background

Following Jakobson, Hayes (1984) claims that sonorant transparency in voice assimilation is a phonological process found in fast speech. He argues that the phonological feature [±voice] spreads through a sonorant to the leftmost obstruent, and connects this with another fact about voicing in Russian – the idiosyncratic behaviour of Russian /v/. The labiodental fricative in Russian undergoes voice assimilation, but never triggers assimilation of a preceding obstruent when occurring before a vowel. Obstruents generally retain an underlying voicing contrast in this position (e.g. *tvorec* [tv] 'creator', *dvorec* [dv] 'palace'). Voice assimilation before /v/, however, is regular when /v/ precedes an obstruent and assimilates (*ot vdovy* [dvd] 'from the widow', *bez vpuska* [sfp] 'without admission').

However, this analysis is based predominantly on cases of incomplete voicing. In order to explain how devoicing might spread through sonorants that are still pronounced with vocal fold vibration, Hayes generalises over these cases and cases of partial devoicing of word-final sonorants. He argues that sonorants can be pronounced with vocal fold vibration, but be phonologically [−voice]. According to Hayes (1984: 325), [−voice] sonorants are characterised by weaker and less regular vibration of the vocal folds than [+voice] sonorants. The other direction of assimilation, i.e. voicing in presonorant obstruents, is not discussed. Unfortunately, no results of acoustic measurements of voicing in obstruents or any demographic information about the language consultants and what variety of Russian they speak are given. Nor does Hayes provide any information about how regular this process is, except that this phenomenon becomes more noticeable in fast speech.

Not every linguist agrees on the existence of sonorant transparency in Russian. Some (Es'kova 1971, Shapiro 1993, Kavitskaya 1999) deny its existence. According to Es'kova (1971: 245), voicing of /t/ in cases like *ot mgly* 'from the haze' cannot occur, because clusters like [dmg] are not possible within a single syllable. Kavitskaya (1999) claims that sonorant transparency is not found in the speech of several language consultants in her study (speakers of the Moscow dialect of Standard Russian), nor in her own speech. Others claim that transparency is possible under certain circumstances. Cho (1990) and Padgett (2002) argue that sonorant transparency to voice assimilation in Russian is a gradient, phonetic phenomenon. Ševoroškin (1971) argues that it is optional. He departs from Hayes, however, in claiming that only phonetically devoiced sonorants can trigger devoicing in preceding obstruents. Thus /z/ in the phrase *iz mxa* 'out of the moss' is voiced if [m] is voiced, but it is voiceless if the sonorant is devoiced: [is m̥xa].

Some cases of voice assimilation before a sonorant followed by an obstruent were investigated by Robblee & Burton (1997). They tested four speakers who pronounced sentences with embedded phrases containing prepositions with voiceless obstruents, *s* 'with, from' and *ot*, before liquid–vowel and liquid–voiced obstruent sequences (e.g. *s lišnim* 'with extra', *s ldiny* 'from the ice') and prepositions with voiced obstruents *iz* 'from', *bez* 'without', *nad* 'over' and *pod* 'under' before liquid–vowel and liquid–voiceless obstruent sequences (e.g. *bez riska* 'without risk', *bez rtuti* 'without mercury'). Mean closure duration and the relative amplitude of low-frequency energy were taken as an indication of the voicing properties of the first obstruent in a cluster. The results show that the second obstruent (C_2) did not affect the laryngeal state of the first obstruent (C_1). Neither mean closure duration nor relative amplitude of /t/ and /d/ differed significantly if the liquid was followed by a vowel or by an obstruent. The two classes of obstruents – voiceless and voiced – remained distinct.

Due to limitations of the design, some important comparisons were not made in Robblee & Burton (1997). First, they did not investigate changes in voicing in obstruents in fast speech. Second, they compared voiced and voiceless obstruents only in potentially assimilating cluster types (voiced–sonorant–voiceless and voiceless–sonorant–voiced). In order to establish the sources of voicing and devoicing in C_1 in obstruent–sonorant–obstruent clusters, it is crucial to compare voicing in presonorant C_1 obstruents before both voiced and voiceless C_2 with voicing in C_1 stops in obstruent clusters. As phonological assimilation in obstruent clusters means that voicing in C_1 is a function of C_2 voicing, the goal of this study is to examine the effects of a sonorant + C_2 obstruent on the voicing properties of C_1 obstruents in consonant clusters across a clitic boundary.

4 Method

4.1 Participants

Fourteen native speakers of Russian, seven males and seven females, participated. Their mean age was 19·0 years (SD = 1·9; range 18–25 years). They were monolingual speakers who had grown up and resided in Tambov, Russia, and spoke educated Standard Russian.[3] The participants

[3] The speakers had learned some English or German in middle and high school; however, the input was not naturalistic, as the foreign language was taught by non-native speakers. None of the participants actively spoke a foreign language on an

had no history of speech or hearing disorders. They were naive as to the purpose of the experiment, and were paid a standard hourly rate for their participation in the study.

After inspection of the recordings, one speaker's data (S6) were excluded, due to consistent deletion of voiceless C_1 obstruents in obstruent–sonorant–obstruent clusters. His data were discarded from the statistical analysis; however, his results are reported in a general discussion of processes that were observed in obstruent–sonorant–obstruent clusters in prepositions.

4.2 Stimuli

The list of stimuli consisted of four phrases with a preposition ending in an underlying voiceless stop (*ot*), and four phrases with a preposition ending in an underlying voiced stop (*nad*). These prepositions preceded nouns beginning with a sonorant–obstruent cluster with a voiced or voiceless C_2: e.g. *nad rtutju* 'over mercury', *ot lgun'ji* 'from the liar'. Thus there were target phrases with four types of obstruent–sonorant–obstruent combinations: voiced–sonorant–voiced (/dlg, dmz/), voiced–sonorant–voiceless (/drt, dmx/), voiceless–sonorant–voiced (/tlg, tmz/) and voiceless–sonorant–voiceless (/trt, tmx/). Eight phrases with the same prepositions before a noun beginning with a single stop were used as a control category (assimilation condition): voiced–voiced (/dg, db/), voiced–voiceless (/dt, dk/), voiceless–voiced (/tg, tb/) and voiceless–voiceless (/tp, tk/): e.g. *nad parom* 'over vapour', *ot gaza* 'from gas'. Heterorganic stops were used to reduce the number of unreleased C_1 stops in clusters (Zsiga 2000). The full list is given in (8). Finally, there were twelve fillers with assorted prepositional phrases unrelated to voice assimilation. The phrases were randomised and presented to the participants as a single set.

(8) *List of target stimuli*

C_1–son–C_2		C_1–C_2	
nad mxom	'over the moss'	nad parom	'over vapour'
ot mxa	'from the moss'	ot para	'from vapour'
nad rtutju	'over mercury'	nad kartoj	'over the map'
ot rtuti	'from mercury'	ot karty	'from the map'
nad lgun'jej	'over the liar'	nad bakom	'over the tank'
ot lgun'ji	'from the liar'	ot baka	'from the tank'
nad mzdoj	'over the bribe'	nad gazom	'over gas'
ot mzdy	'from the bribe'	ot gaza	'from gas'

everyday basis (see Fowler *et al.* 2008 for a detailed discussion of conditions of L2 transfer).

Russian speakers in the United States were not used, to avoid possible effects of a second language. As Dmitrieva *et al.* (2010) show, speakers of Russian begin to pronounce voiced and voiceless sounds in their native language in a way which is more similar to English sounds after staying in the United States for several months.

4.3 Procedure and measurements

The participants were asked to read phrases aloud in three speaking-rate conditions. In condition 1 (list rate), the target phrases were pronounced carefully as a word list. In condition 2 (slow rate), the phrases were placed in a carrier phrase *Skaži __ ješče raz* 'Say __ once again', and were pronounced at a comfortable tempo. In condition 3 (fast rate), the phrases were placed in the same carrier phrase, and pronounced quickly. The speakers were instructed to say the phrases as if they were trying to say something important to a person who was leaving the room.

For each condition, the speakers read the materials three times, but only the second and third readings were recorded. 96 test phrases (16 phrases × 3 conditions × 2 readings) for each speaker were recorded; thus the total number of target segments was 1248. 40 tokens were discarded, due to absence of release, nasalisation, deletion or metathesis. 1208 tokens thus remained for the statistical analysis.

The speakers were digitally recorded in a quiet room, using a one-point condenser Shure WH30XLR microphone connected to an M-Audio MobilePre USB soundcard through an XLR interface. The microphone was placed 20 mm from the right corner of the mouth. The recording was made at 44,100 Hz and then downsampled at 22,050 Hz for acoustic analysis. A digital high-pass filter with a 70 Hz cut-off frequency was applied to the speech waveform. The high-pass filter served to reduce oscillations resulting from room vibration, as well as to suppress the microphone air-blast artefact associated with plosive speech productions.

The obstruent boundaries were set manually in Praat (Boersma & Weenink 2011). To investigate whether voice assimilation occurred in obstruent clusters, acoustic measurements of the first and second obstruents in the cluster (C_1 and C_2) were performed. Changes in various acoustic measurements are diagnostic of voice assimilation in C_1: closure duration, voicing duration, voicing ratio, duration of a preceding vowel and F1 frequency. Both the waveform and the spectrogram were used to set the obstruent boundaries. Figure 1a illustrates an underlying voiced C_1 stop before a sonorant and a voiceless C_2 stop; Fig. 1b illustrates an underlying voiced C_1 stop before a voiceless C_2 stop in an assimilating obstruent–obstruent cluster. The beginning of the stop closure was marked at the end of the F2 structure, which typically coincides with a significant drop in amplitude of vocal fold vibration (Jessen 1998). The end of the closure was marked at the beginning of the release burst. Closure duration and duration of voicing of the target stops were measured. The voicing ratio was then calculated as a ratio of voicing duration to closure duration.

The onset and offset of the vowel were marked at the beginning and end of F2, which typically coincided with high amplitude of vocal fold vibration. When a nasal preceded a vowel, the boundary was set at the point where there was a noticeable change of the formant structure and

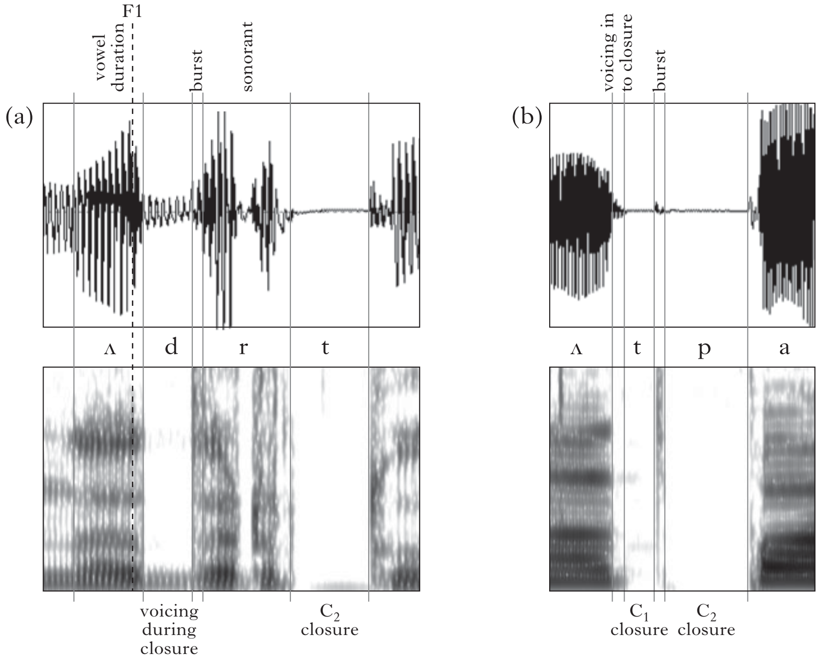

Figure 1

Examples of important acoustic measurements for voiced and voiceless stops. Tokens (a) *nad rtutju* 'over mercury', spoken by S10 (male) at fast rate (no assimilation; fully voiced C_1 stop before a voiceless C_2 stop), and (b) *nad parom* 'over vapour', spoken by S1 (female) at fast rate (assimilation; voiceless C_1 stop before a voiceless C_2 stop).

amplitude of vocal fold vibration. F1 was measured at a point 10 ms before vowel offset.

5 Results

The objective of the analysis was to determine whether voice assimilation takes place in consonant clusters across a prepositional boundary at different speaking rates. If the first obstruent in the cluster (C_1) assimilates in voicing, the voicing properties of this segment should be consistent with the voicing properties of the second obstruent in the cluster (C_2). If, in contrast, the voicing properties of C_1 are consistent with the underlying specification for voice, this can be taken as evidence for absence of voice assimilation.

Several acoustic measurements were used to investigate the voicing properties of stops: voicing duration, closure duration, voicing ratio, duration of a preceding vowel and F1 frequency. These measurements were tested for effects of C_1 underlying voicing (voiced, voiceless), C_2 voicing (voiced, voiceless), cluster type (with, without a sonorant) and speaking rate (slow, fast). An effect of C_2 for all cues would indicate voice assimilation and sonorant transparency. If, however, sonorant transparency is not found in the data, cluster type is predicted to interact with C_1 voicing and C_2 voicing. For clusters with a sonorant, an effect of C_1 voicing and no effect of C_2 voicing are expected, indicating preservation of the underlying contrast and no assimilation. For clusters without a sonorant, a effect of C_2 voicing is expected, but no effect of C_2 voicing, indicating voice assimilation. The presence of sonorant transparency can be established if an effect of C_2 voicing but no effect of C_1 voicing is found in both types of clusters.

The analysis involved several stages. First, the effect of the speech tempo on production was investigated, to determine whether the manipulation of the speaking rate had the intended effect. Next, the voicing properties of C_2 were analysed, to establish whether the segments that might determine the results of voice assimilation remained stable. Finally, the C_1 was analysed, to assess the degree of assimilation in C_1 in different speaking-rate conditions. The C_1–sonorant–C_2 clusters were compared to the C_1–C_2 clusters, to determine whether the intervening sonorant prevented voice assimilation. A preliminary test showed that duration of voicing was not significantly different in the list and slow speech conditions ($T(12) = 0{\cdot}51$, $p = 0{\cdot}619$); thus the data for the list condition were dropped in favour of analysis in more realistic speaking conditions.

5.1 Effect of speaking rate on phrase duration

The first test examined whether the manipulation of speaking rate had the intended effect. The total phrase duration was used as a proxy for speaking rate; shorter duration was expected with faster reading.[4] A repeated measures ANOVA was used to evaluate a (within-subjects) effect of speaking rate conditions (slow, fast) on word duration. Figure 2 summarises the results.

A highly significant main effect of speaking rate was found ($F(1,12) = 146{\cdot}4$, $p < 0{\cdot}001$). As expected, all speakers' phrases had a shorter duration in the fast condition ($M = 489$ ms, SD = 48) than in the slow condition ($M = 646$ ms, SD = 53), a mean difference exceeding 150 ms.

[4] The duration of phrases with both voiced and voiceless initial stops was measured from the release point. Another possibility was to include prevoicing in phrase duration for cases with initial voiced stops. Almost identical results were obtained using the two approaches: the duration of target phrases was 30% less in fast speech than in slow speech.

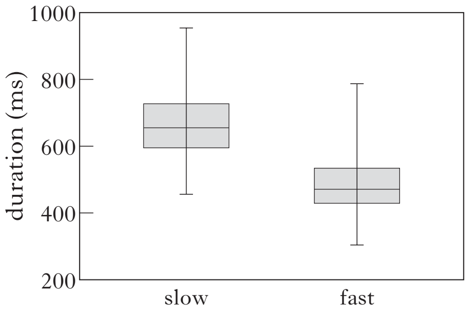

Figure 2
Mean phrase duration in slow and fast speaking rate conditions.

5.2 Voicing in C_2 obstruents

The next set of tests examined voicing in the second consonant in a cluster (C_2). For the purposes of the study, it was important to establish whether voicing in C_2 was a constant parameter or varied unpredictably. The latter situation would considerably complicate the analysis of voicing in C_1 stops, as it would require testing changes of voicing in C_1 in individual matched pairs with C_2.

Because a variety of unmatched stops (e.g. [t] *vs.* [g]) and fricatives (e.g. [x] *vs.* [z]) were used in the stimuli, direct comparison of all temporal cues in these obstruents was not appropriate. Such comparison would find differences (e.g. in closure duration) which are due to manner (stop *vs.* fricative) or place of articulation (dental *vs.* velar) rather than to underlying voicing. Thus only duration of voicing and the proportion of voicing duration to closure duration (voicing ratio) of the two categories of obstruents was compared across two speaking-rate conditions. The results are summarised in Fig. 3.

A repeated measures ANOVA with underlying voicing (voiced, voiceless) and speaking rate (slow, fast), was performed on each measurement. Main effect of underlying voice was significant for both acoustic measurements: voicing duration ($F(1,12) = 723{\cdot}9$, $p < 0{\cdot}0001$) and voicing ratio ($F(1,12) = 1684$, $p < 0{\cdot}0001$). As expected, C_2 obstruents retained their underlying specification for voice. Underlying voiced obstruents were voiced during 94% of their closure/frication, averaging 72 ms (SD = 27); underlying voiceless obstruents were voiced for 1% of their closure/frication, averaging 1 ms (SD = 4).

An effect of rate ($F(1,12) = 89{\cdot}2$, $p < 0{\cdot}0001$) and an interaction with underlying voicing ($F(1,12) = 79{\cdot}1$, $p < 0{\cdot}0001$) were obtained for voicing duration, revealing that it was shorter in fast speech ($M = 61$ ms, SD = 24) than in slow speech ($M = 82$ ms, SD = 27) only in voiced C_2 obstruents. Duration of voicing in voiceless C_2 obstruents did not change as a function of speaking rate. The differences in duration between voiced and voiceless

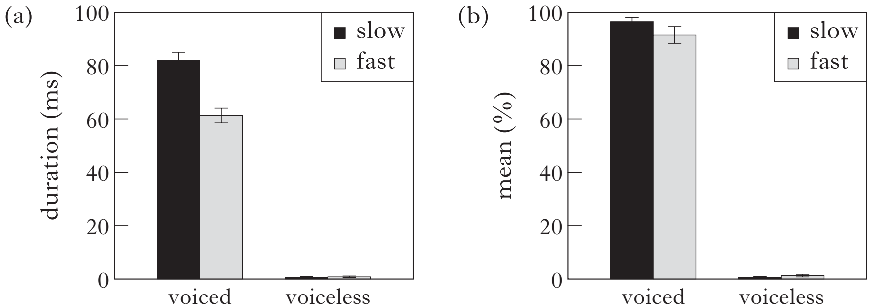

Figure 3

(a) Mean voicing duration and (b) mean voicing ratio in underlying voiced and voiceless C_2 obstruents in the slow and fast rate conditions.

obstruents were nevertheless significant in both speaking-rate conditions (slow: $T(1,12)=26{\cdot}87$, $p<0{\cdot}0001$; fast: $T(1,12)=22{\cdot}14$, $p<0{\cdot}0001$).

No effect of rate ($F(1,12)=2{\cdot}42$, $p=0{\cdot}146$) was obtained for voicing ratio: voicing ratio in C_2 obstruents did not change in different speaking-rate conditions. Thus the results suggest that voicing in C_2 obstruents remains stable, which ensures a correct analysis of voicing in C_1 obstruents.

5.3 Voicing in C_1 stops

The next step of the analysis examined cues to voicing in C_1 stops. In particular, the closure voicing was examined, along with three secondary cues: closure duration, duration of a preceding vowel and F1 frequency. In a by-subject analysis, each cue was examined using a repeated measures ANOVA with C_1 underlying voicing (voiced, voiceless), cluster type (with a sonorant, without a sonorant), C_2 voicing (voiced, voiceless) and speaking rate (slow, fast) as within-subject factors. In a by-item analysis, a repeated measures ANOVA with speaking rate (slow, fast) as a within-subject factor and cluster type (with a sonorant, without a sonorant), underlying voicing (voiced, voiceless) and C_2 voicing (voiced, voiceless) as between-subject factors was performed on each cue. The summary for these ANOVAs is shown in Table I, and the most important findings are discussed below.

5.3.1 *Main cue: voicing during closure.* Acoustic measurements of voicing duration are summarised in Table V in the Appendix. Crucially, the statistical tests revealed significant interactions of cluster type with C_1 and C_2 in both by-subject and by-item analyses (see Fig. 4a). This means that C_1 obstruents retained an underlying voicing contrast when they were in a presonorant position (voiced: $M=49$ ms, SD $=14$; voiceless: $M=18$ ms, SD $=7$; $F_1(1,12)=144{\cdot}4$, $p<0{\cdot}001$; $F_2(1,4)=160{\cdot}8$,

		cues			
effects	statistic (df)	voicing duration	closure duration	vowel duration	F1
underlying voicing	$F_1(1,12)$ $F_2(1,8)$	166·10*** 124·60***	3·57 2·39	49·91*** 218·60***	<1 2·28
cluster type	$F_1(1,12)$ $F_2(1,8)$	<1 <1	12·08** 11·63**	<1 1·06	21·31** 19·20**
C_2 voicing	$F_1(1,12)$ $F_2(1,8)$	109·20*** 98·20***	8·36* 3·76	1·60 3·03	<1 <1
rate	$F_1(1,12)$ $F_2(1,8)$	8·64* 38·30***	49·91*** 180·70***	11·61** 151·30***	32·56*** 136·80***
underlying voicing × cluster type	$F_1(1,12)$ $F_2(1,8)$	95·95*** 103·60***	<1 <1	5·21* 11·06*	5·92* 2·24
C_2 voicing × cluster type	$F_1(1,12)$ $F_2(1,8)$	127·10*** 115·50***	2·30 <1	<1 <1	<1 2·66
underlying voicing × C_2 voicing	$F_1(1,12)$ $F_2(1,8)$	<1 <1	5·79* <1	<1 <1	<1 <1
underlying voicing × rate	$F_1(1,12)$ $F_2(1,8)$	<1 9·56*	3·27 6·33*	<1 3·13	<1 1·71
cluster type × rate	$F_1(1,12)$ $F_2(1,8)$	1·97 8·57*	1·04 <1	1·29 5·07	3·23 4·51
C_2 voicing × rate	$F_1(1,12)$ $F_2(1,8)$	21·80** 43·10***	<1 1·69	<1 <1	<1 <1

Table I

Summary of ANOVAs examining effects of underlying voicing (two levels), cluster type (two levels), C_2 voicing (two levels) and speaking rate (two levels) on acoustic cues in C_1 stops in prepositions. F_1 and F_2 values are shown. Significant values are indicated by * ($p < 0.05$), ** ($p < 0.01$) and *** ($p < 0.001$).

$p < 0.001$), with no effect of C_2 voicing ($F_1 < 1$; $F_2 < 1$). In obstruent–obstruent clusters, in contrast, no effect of underlying voicing in C_1 obstruents was found (voiced: $M = 34$ ms, SD = 7; voiceless: $M = 31$ ms, SD = 8; $F_1 < 1$; $F_2 < 1$), but the effect of C_2 was highly significant (voiced: $M = 47$ ms, SD = 9; voiceless: $M = 18$ ms, SD = 7; $F_1(1,12) = 220.5$, $p < 0.001$; $F_2(1,4) = 365.2$, $p < 0.001$).

This strongly suggests that voice assimilation in Russian is found only in obstruent–obstruent clusters, whereas in obstruent–sonorant–obstruent

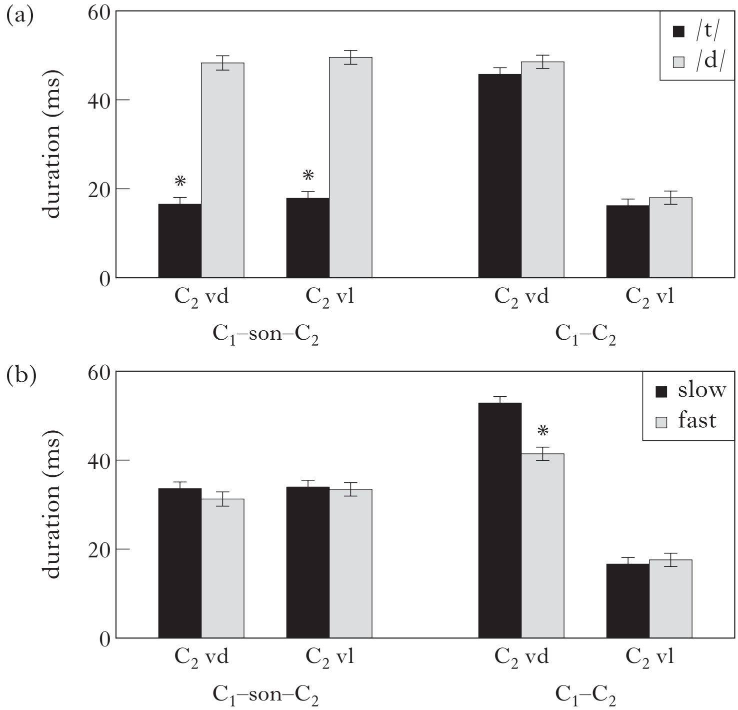

Figure 4

Effects of (a) cluster type and (b) speaking rate on voicing duration in C_1 stops, pooled across 13 speakers.

clusters the rightmost obstruent does not affect voicing in C_1 obstruents, and thus claims about voice assimilation and sonorant transparency in such clusters are not supported.

Speaking rate affected voicing in C_1 ($F_1(1,12) = 8{\cdot}64$, $p < 0{\cdot}05$), but due to a significant rate × C_2 voice × cluster type interaction ($F_1(1,12) = 15{\cdot}14$, $p < 0{\cdot}01$; $F_2(1,8) = 22{\cdot}63$, $p < 0{\cdot}01$), the effects of rate in clusters with and without a sonorant were investigated separately. Results are shown in Fig. 4b.

In obstruent–obstruent clusters, rate interacted with C_2 voice ($F_1(1,12) = 40{\cdot}69$, $p < 0{\cdot}001$; $F_2(1,4) = 82{\cdot}31$, $p < 0{\cdot}001$) rather than with underlying voice ($F_1 < 1$; $F_2 < 1$), revealing that the duration of voicing changed as a function of speaking rate only in phonetically voiced obstruents before voiced C_2 (slow: $M = 53$ ms, SD = 10; fast: $M = 42$ ms, SD = 8; $T(1,12) = 5{\cdot}96$, $p < 0{\cdot}001$). Voicing in voiceless obstruent clusters did not change as a function of speaking rate ($T < 1$).

In clusters with presonorant C_1 obstruents, a different pattern was observed. Rate did not interact with C_2 ($F_1 < 1$; $F_2 < 1$), and mean difference (5 ms) between slow and fast rates observed in voiced presonorant

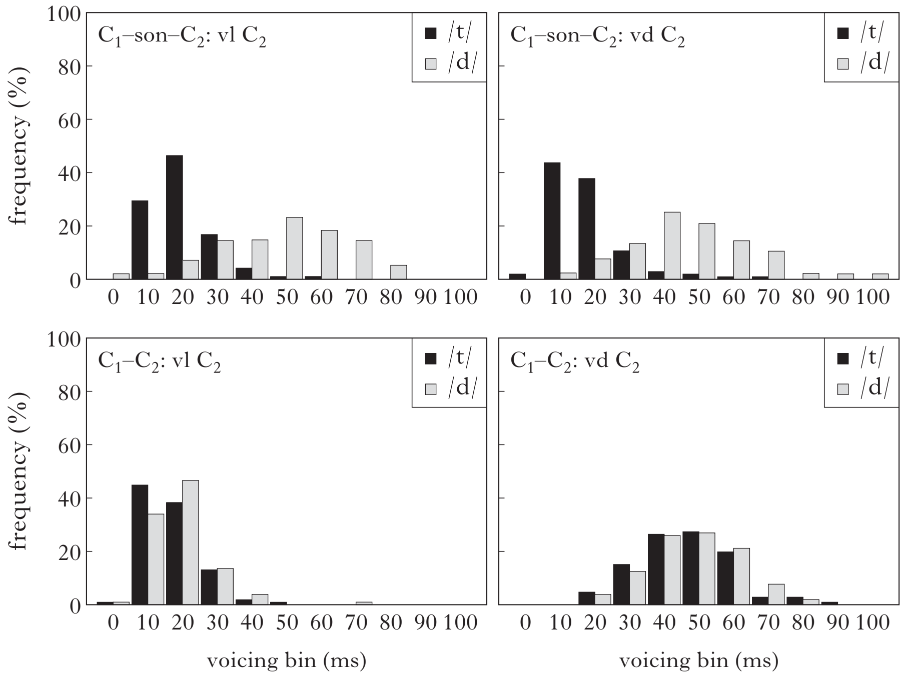

Figure 5

Distributions of voicing duration in C_1 stops in prepositions, broken down by cluster type (upper row: C_1–son–C_2; lower row: C_1–C_2) and C_2 obstruent (left column: voiceless; right column: voiced).

obstruents (slow: $M = 51$ ms, $SD = 13$; fast: $M = 46$ ms, $SD = 15$) was significant in a by-item analysis ($T(1,3) = 4{\cdot}45$, $p < 0{\cdot}05$) but it did not reach significance level in a by-subject analysis ($T(1,12) = 1{\cdot}08$, $p = 0{\cdot}300$). No significant difference in voicing duration between the slow and fast conditions was observed in underlying voiceless presonorant obstruents ($T_1(1,12) < 1$; $T_2(1,3) = 1{\cdot}12$, $p = 0{\cdot}345$).

Thus the results suggest that changes in duration of phonetic voicing were different in the two types of clusters. In the assimilating obstruent–obstruent clusters, the changes due to rate manipulation were found in *voicing affected by C_2 obstruents*, but in obstruent–sonorant–obstruent clusters, no significant change of voicing as a function of speaking rate was found.

5.3.2 *Distribution of voicing duration.* While the main effect of underlying voicing on closure voicing was highly significant for obstruent–sonorant–obstruent clusters, this result does not show whether there was any overlap in the distributions. It is important to evaluate whether this cue is an unambiguous marker of voicing. The distributions

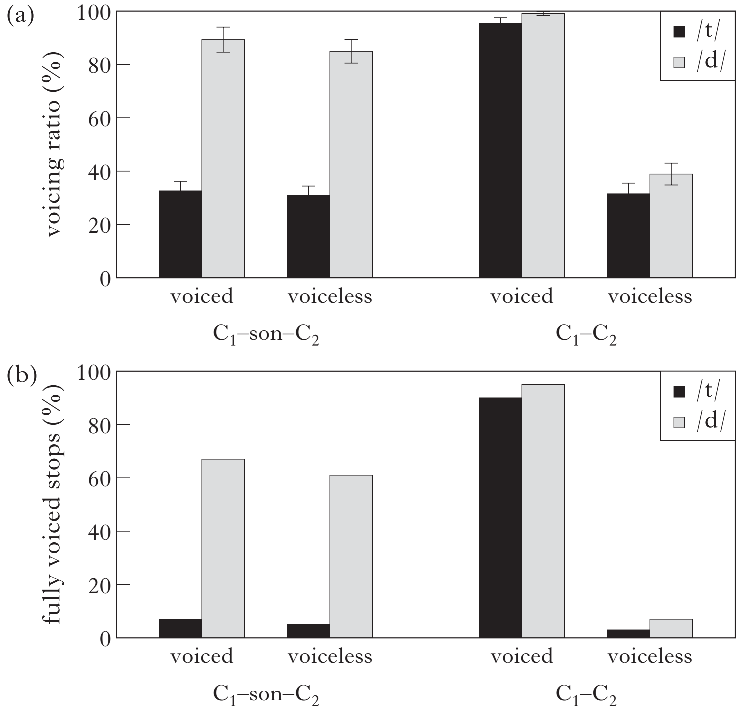

Figure 6

(a) Voicing ratios and (b) percentage of fully voiced C_1 stops in clusters, broken down by C_2 obstruent and cluster type, pooled across 13 speakers.

were thus computed for voicing during closure values in 10 ms bins, centred at 0, 10, 20, etc., as shown in Fig. 5.

The distributions revealed that overlap of voicing duration in underlying /d/ and /t/ was complete in obstruent–obstruent clusters, but for underlying /d/ and /t/ in obstruent–sonorant–obstruent clusters there were two distinct modes: one with a peak at 20 ms for /t/, and the other with a peak at 45 ms for /d/. This confirms the results of statistical tests, and suggests unambiguous voice assimilation in obstruent–obstruent clusters, but preservation of the underlying contrast in obstruent–sonorant–obstruent clusters.

The two types of clusters had very similar distributions in terms of phonetic voicing. The categorical boundary between phonetically voiced and voiceless obstruents was established at 35 ms, using the formula 'mean + 2 SD' (Slis 1986). For both cluster types, there was partial overlap: roughly 25 % of [d]'s had voicing durations shorter than 35 ms, and overlapped with [t]'s. About 10 % of [t]'s had voicing durations longer than 35 ms, and overlapped with [d]'s.

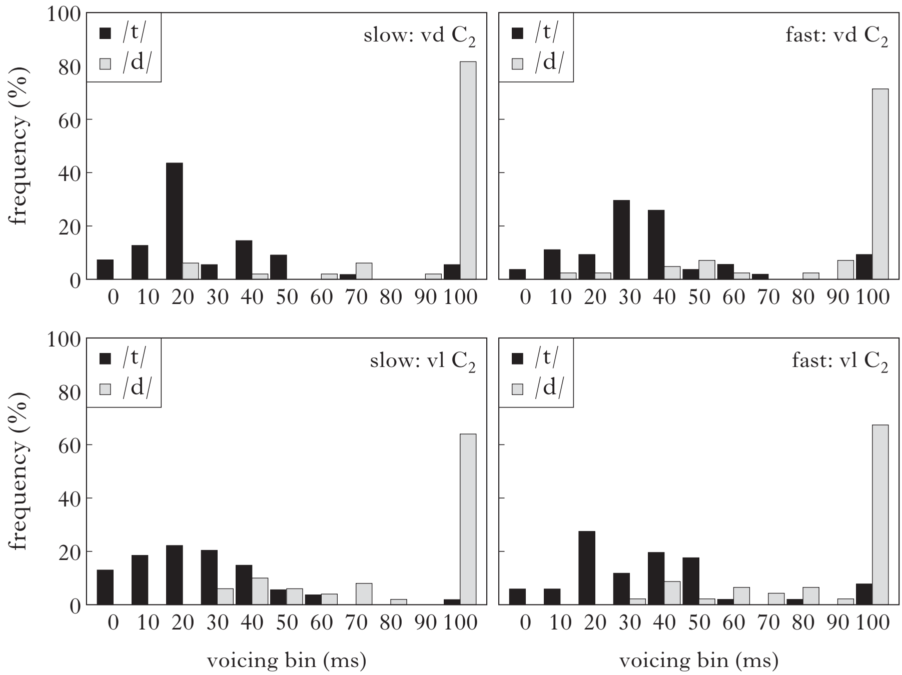

Figure 7

Distributions of voicing ratios in presonorant C_1 stops in clusters, broken down by C_2 obstruent (upper row: voiced; lower row: voiceless) and speaking rate (left column: slow; right column: fast), pooled across 13 speakers.

5.3.3 *Voicing ratio.* As distribution of voicing durations revealed partial overlap between phonetically voiced [d] and voiceless [t], it was important to examine the percentage of voicing during closure in these stops, and the number of partially voiced stops. Voicing ratios were calculated as a ratio of voicing duration to closure duration. A summary of voicing ratios is given in Fig. 6a, while Fig. 6b summarises the calculations for fully voiced C_1 stops.

The distributions of voicing ratios in presonorant C_1 obstruents (Fig. 7) show that the underlying voicing contrast was not neutralised in presonorant /t/ and /d/. The distributions are bimodal, but there was some overlapping between underlying voiceless and voiced obstruents in all presonorant clusters, suggesting that some C_1 obstruents had gradient changes in phonetic voicing.

Crucially, however, these changes in voicing ratios in C_1 obstruents were not caused exclusively by voicing of the following C_2 obstruent, and thus cannot be interpreted as voice assimilation. No association was found between phonetic voicing, which was established as a voicing ratio lower than 50% for voiceless obstruents and higher than 50% for

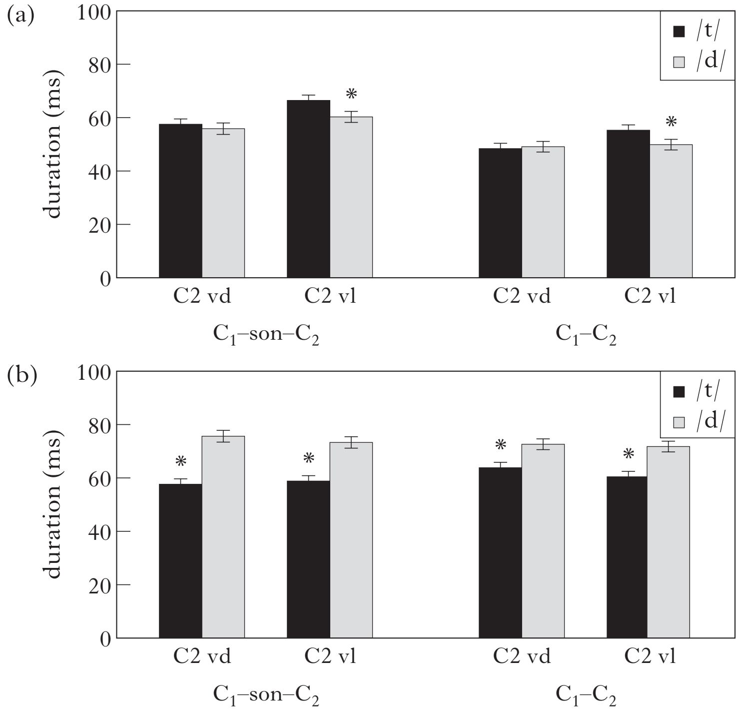

Figure 8

Effects of cluster type on (a) closure duration in C_1 stops and (b) preceding vowel duration.

voiced obstruents, and the voicing category of C_2 ($\chi^2(1) = 0{\cdot}16$, $p = 0{\cdot}689$).[5] Intriguingly, 2 % of underlying presonorant /t/'s in slow speech and 8 % of /t/'s in fast speech were produced with a fully voiced closure before voiceless C_2, i.e. in the environment which excludes phonetic and phonological voicing. Similarly, underlying presonorant /d/ was not fully voiced in 18 % of cases in slow speech and in 29 % of cases in fast speech

[5] An anonymous reviewer points out that the threshold for phonetic voicing (e.g. lower or higher than 50 %) is arbitrary. This threshold is motivated by the criterion used in Slis (1986), who established the boundary between voiced and voiceless obstruents at 'mean + 2 SD' of the duration of voice tail in voiceless tokens. In this study, this translates into a boundary at 40 ms of voice tail duration, with voicing ratio (VR) = 58 % for presonorant /t/ before a voiceless C_2, i.e. in the environment that excludes phonological assimilation. Notice that this ratio is slightly higher than the ratio for single prevocalic/presonorant voiceless stops in Russian. According to the data in Ringen & Kulikov (2012: 280), the 'mean + 2 SD' boundary can be calculated at VR = 46 %. This difference might be due to the fact that C_1 stops in long clusters have shorter closure, while the duration of voice tail is a relatively stable value (Kulikov 2012). Thus the boundary at VR = 50 % used in this study is a viable estimate of phonetic voicing in presonorant stops.

before voiced C_2, suggesting that shorter voicing in such clusters is not a result of assimilatory devoicing.

5.3.4 *Secondary cues: closure duration.* Table VI (see the Appendix) summarises the results of acoustic measurements of closure duration in C_1 stops.

The statistical tests revealed (Fig. 8a) that an effect of cluster type was obtained, but no main effects of underlying and C_2 voicing or interaction. Stops were longer when they preceded a sonorant ($M = 60$ ms, $SD = 15$) and shorter in obstruent clusters ($M = 51$ ms, $SD = 9$). This is consistent with the pattern observed in word-internal consonant clusters (Kulikov 2012): speakers of Russian produce longer stops in presonorant position than in stop clusters. As expected, speaking rate affected closure duration ($F(1,12) = 49{\cdot}91$, $p < 0{\cdot}001$): stops were longer in slow speech ($M = 61$ ms, $SD = 12$) and shorter in fast speech ($M = 50$ ms, $SD = 12$).

5.3.5 *Secondary cues: vowel duration and F1 frequency.* Results for the duration of vowels preceding C_1 stops are shown in Table VII in the Appendix. Figure 8b summarises the results of the statistical tests. Due to a significant underlying voice × cluster type interaction, each cluster type was examined separately.

The effect of underlying voice was obtained for both clusters, but the difference was greater before presonorant C_1 obstruents (voiced: $M = 73$ ms, $SD = 15$; voiceless: $M = 58$ ms, $SD = 13$; $F_1(1,12) = 42{\cdot}27$, $p < 0{\cdot}001$; $F_2(1,4) = 111{\cdot}2$, $p < 0{\cdot}001$) and smaller before obstruent–obstruent clusters (voiced: $M = 72$ ms, $SD = 11$; voiceless: $M = 62$ ms, $SD = 14$; $F_1(1,12) = 33{\cdot}93$, $p < 0{\cdot}001$; $F_2(1,4) = 124{\cdot}8$, $p < 0{\cdot}001$).[6]

A marginal effect of C_2 was observed only in obstruent–obstruent clusters (voiced: $M = 68$ ms, $SD = 13$; voiceless: $M = 66$ ms, $SD = 12$; $F_1(1,12) = 4{\cdot}77$, $p = 0{\cdot}05$; $F_2(1,4) = 5{\cdot}36$, $p = 0{\cdot}082$). No effect of C_2 was found in vowels before a cluster with an intervening sonorant ($M = 66$ ms, $SD = 15$; $F_1 < 1$; $F_2 < 1$).

Speaking rate affected vowel duration, and did not interact with underlying voice or C_2 voice: vowels were longer in slow speech ($M = 72$ ms, $SD = 14$) than in fast speech ($M = 61$ ms, $SD = 13$).

Results for F1 frequency are shown in Table VIII in the Appendix. The statistical test found that only the effect of speaking rate was significant for both cluster types. F1 frequencies were different in fast speech than in slow speech (slow: $M = 548$ Hz, $SD = 95$; fast: $M = 496$ Hz, $SD = 76$).

Thus the results suggest that the two types of clusters were different. No influence of C_2 was found in secondary cues in clusters with an intervening sonorant.

[6] The significant effect of vowel duration before obstruent–obstruent clusters would suggest incomplete neutralisation. The problem of incomplete neutralisation in cases of voice assimilation is discussed at length in Kulikov & McMurray (in preparation).

5.4 Variation in voicing duration in presonorant tokens

Although no effect of C_2 on voicing in C_1 obstruents was found in obstruent–sonorant–obstruent clusters, the results show that speakers produced at least a few presonorant C_1 tokens with greater variation in voicing duration. Some voiceless C_1 obstruents had a higher voicing ratio (more than 50 %) than typical presonorant voiceless tokens; some voiced C_1 obstruents were produced with incomplete voicing during closure. Such tokens were evenly distributed within the whole range of voicing ratios, which suggests that this is a gradient phonetic phenomenon. Waveforms and spectrograms of two such tokens are shown in Fig. 9a (longer than average voicing in voiceless C_1) and Fig. 9b (shorter than average voicing in voiced C_1).

Apparently, in the past, such cases have been interpreted as involving 'sonorant transparency', and it was claimed that there is a phonological rule of assimilation through a sonorant in Russian. However, the results of this study clearly show that such interpretation is not viable. First, variation in voicing duration is not determined by the rightmost obstruent in the cluster. As shown in the previous section, devoicing in presonorant underlying /d/ was observed in clusters with voiced and voiceless C_2. Second, these few examples do not represent a pervasive pattern of voice assimilation, as variation in voicing duration was observed in a small subset of clusters with a sonorant (14 % of tokens) across all speaking rates.

Variation in voicing duration in obstruent–sonorant–obstruent clusters occurs along two lines: (i) patterns of consonant modification, and (ii) individual variation in speakers. Inspection of the data shows that variation in voicing duration is not the only 'noise' found in obstruent–sonorant–obstruent clusters. Table II summarises types of modification of the consonants in such clusters.[7]

Although the experiment was not designed to account for these modifications, the typical cases are reported in this paper, as these results may provide insights into the nature of such variation. Changes in voicing duration and nasalisation were found in presonorant C_1 obstruents, and sonorants, when modified, were usually devoiced.[8] The changes sometimes affected both C_1 and the sonorant. In some clusters, nasalisation of [d] or [t] coincided with denasalisation and devoicing of [m], resulting in 'nasal switch' (e.g. /nad mxom/ → [nanpxom]). Metathesis occurred in [dmx] and [dmz] clusters: /nad mxom/ → [danmxom], /nad mzdoj/ → [danmzdoj].[9] Apparently, these modifications are driven by the

[7] Robblee & Burton (1997) report similar modifications, but they do not quantify them. An anonymous reviewer suggests that the tokens with variation should be analysed to determine factors that might explain variation in voicing. Because of the small number of such tokens in the sample, the results of such analysis might not be reliable.

[8] A sonorant was considered devoiced if it had a voicing ratio lower than 100 %.

[9] Metathesis occurred more often in clusters with a C_1 fricative, where C_1 metathesised with the following sonorant: /iz mxa/ → [imsxa], /s mxom/ → [msxom]. These cases are not discussed here.

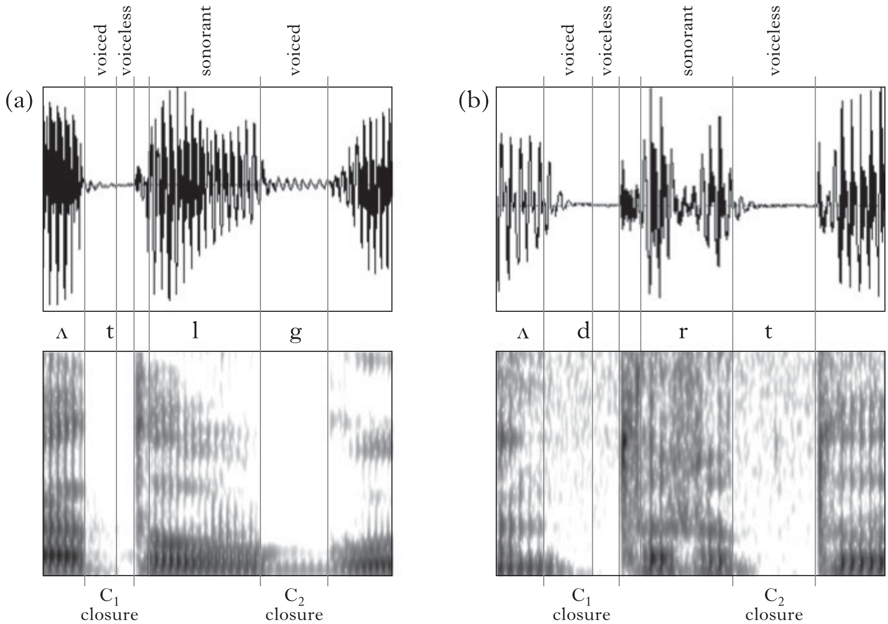

Figure 9

Examples of tokens with variation in duration of voicing: (a) *ot lgun'ji* 'from the liar', spoken by S11 (male) at fast rate (voicing of /t/ before a voiced C_2) and (b) *nad rtutju* 'over mercury', spoken by S9 (male) at fast rate (devoicing of /d/ before a voiceless C_2).

	C_1		sonorant		
modification	/t/	/d/	/r/	/l/	/m/
changes in voicing duration in C_1	10	21			
devoicing in sonorant			21		13
nasalisation in C_1	6	26			
denasalisation in sonorant					8
place assimilation					4
metathesis		2			
deletion	4	3		1	

Table II

Modification of C_1 stops and sonorants in obstruent–sonorant–obstruent clusters, pooled across 14 speakers in slow and fast rate conditions. The total number of clusters examined was 435.

	sonorant voicing		
phonetic voicing in C_1	voiced	devoiced	*total*
voiced (voicing ratio > 50%)	174	10	184
voiceless (voicing ratio ≤ 50%)	196	12	208
total	370	22	392

Table III

Phonetic voicing in C_1 stops before voiced and devoiced sonorants in obstruent–sonorant–obstruent clusters.

	voicing duration				voicing ratio			
	underlying voice		C_2 voice		underlying voice		C_2 voice	
speaker	*F*	df	*F*	df	*F*	df	*F*	df
S2	35·4***	1,31	<1	1,31	55·4***	1,31	2·43	1,31
S4	76·3***	1,33	33·6***‡	1,33	67·4***	1,33	29·7***‡	1,33
S7	43·6***	1,28	<1	1,28	25·3***	1,28	<1	1,28
S9	30·5***	1,28	<1	1,28	23·8***	1,28	4·14†	1,28
S12	16·9***	1,32	<1	1,32	17·7***	1,32	1·96	1,32

Table IV

Effects of underlying voicing and C_2 voicing on duration of voicing and voicing ratio in clusters with presonorant C_1 stops for five speakers. † $p = 0{\cdot}054$; ‡ longer voicing in C_1 stops before voiceless C_2. Significant values are indicated by *** ($p < 0{\cdot}001$).

tendency to simplify long consonant clusters, resulting in a simpler and less marked syllable structure.

Crucially, however, the majority of C_1 obstruents retained their laryngeal specifications before a sonorant. Even devoicing of a sonorant did not necessarily cause devoicing in a preceding C_1 obstruent. As shown in Table III, surface voicing in C_1 obstruents is not associated with surface voicing in an adjacent sonorant ($\chi^2(1) = 0{\cdot}02$, $p = 0{\cdot}532$). This pattern is consistent with presonorant faithfulness and absence of assimilation.

Variation was also observed among the speakers. They varied in their tendencies to devoice or voice C_1 obstruents in clusters where variation in voicing duration was found. Observations of individual tokens revealed that three speakers – S3, S5 and S10 – did not show any evidence of variation in voicing duration. S4, S7, S8 and S9 never voiced, and S2,

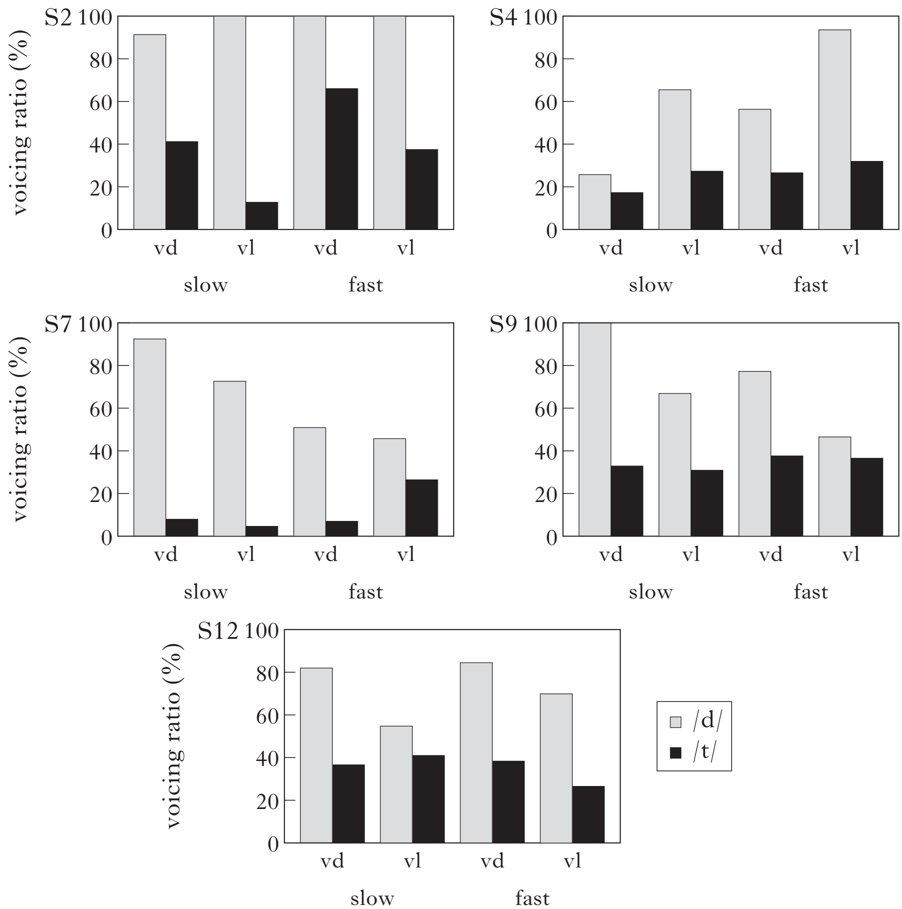

Figure 10

Individual voicing ratios for presonorant C_1 stops in slow and fast conditions for five speakers (S2, S4, S7, S9 and S12).

S11, S13 and S14 never devoiced. Only S1 and S12 produced some voicing and devoicing, although they were not consistent in different speaking-rate conditions.[10] Five speakers – S2, S4, S7, S9 and S12 – showed patterns that might resemble the 'sonorant transparency' pattern previously reported in literature. Their voicing ratios are presented in Fig. 10. However, the individual analyses of results for these speakers do not suggest that variation in production of voicing in presonorant stops is triggered by the C_2 obstruent, as shown in Table IV.

[10] The results of a pilot study (Kulikov 2010) suggest that speakers can also vary in their tendencies to devoice or voice C_1 stops as opposed to C_1 fricatives. Some speakers in that study had variation only in stops and some only in fricatives.

Separate univariate ANOVAs for each speaker with rate (slow, fast), underlying voice (voiced, voiceless) and C_2 voice (voiced, voiceless) as factors were used to investigate the influence of the rightmost obstruent on voicing duration and voicing ratios in presonorant C_1 obstruents. C_2 voicing does not affect voicing duration in presonorant C_1 obstruents, it only marginally ($p = 0{\cdot}054$) affects voicing ratio in S9's obstruents and is manifested as incomplete voicing during closure. Significant effects of C_2 on voicing duration and voicing ratio obtained for speaker S4 in fact reveal an unusual inverse pattern, with longer duration of voicing before voiceless C_2 (voiceless: $M = 41$ ms, SD = 21; voiced: $M = 23$ ms, SD = 13). Intriguingly, S4 produced all underlying /d/'s before a voiced C_2 with a voiceless closure. Thus patterns of individual variation and modification of consonants in obstruent–sonorant–obstruent clusters also fail to reliably indicate phonological assimilation correlated with voicing in C_2.

6 Discussion and conclusion

The results of the experiment do not support the claim that voice assimilation through a sonorant consonant is a phonological rule of Russian. Contrary to this claim, the results of the tests strongly suggest that no consistent phonological change of underlying voicing occurred in C_1 obstruents in obstruent–sonorant–obstruent clusters in response to the voicing of C_2. Such an effect would be a natural condition of phonological assimilation in voicing. Recall that a strong effect of C_2 voicing was predictably found in obstruent–obstruent clusters, where voice assimilation is a regular process. The surface voicing of C_1 stops in these clusters was contingent on the voicing category of the rightmost obstruents. Duration of voicing in underlying /t/ before voiced C_2 was increased, to produce a voiced closure; duration of voicing in underlying /d/ before voiceless C_2 was reduced to a short voice tail, to produce a voiceless closure. But presonorant C_1 obstruents in obstruent–sonorant–obstruent clusters did not change duration of closure voicing, just as in other presonorant positions in Russian. In addition, no effect of C_2 voicing was obtained for other cues (e.g. vowel duration). These findings do not fully support Ševoroškin (1971), who claims that C_1 devoicing occurs only before voiceless sonorants. Although some devoiced C_1 obstruents were indeed found before devoiced sonorants, this was not a regular pattern.

The findings of this study are in line with the acoustic study of sonorant transparency in Russian in Robblee & Burton (1997) and the recent acoustic study of Polish presonorant stops in Strycharczuk (2012). Russian and Polish speakers show a strong tendency to preserve the underlying contrast in presonorant position. This pattern is not consistent with the model of phonological assimilation, which would predict neutralisation of the contrast and little or no difference in the realisation of voicing in assimilated (devoiced) and underlying voiceless obstruents.

These results cast doubt on the idea that propagation of voicing through a sonorant consonant is a viable phonological process. The observed pattern in obstruent–sonorant–obstruent clusters is consistent with presonorant faithfulness rather than with voice assimilation. Proponents of voice assimilation through a sonorant in Russian can still argue that this principle is needed to explain voice assimilation before /v/. Indeed, obstruents usually fully assimilate before /v/ followed by another obstruent (Avanesov 1968, Hayes 1984; though see Panov 1967), but they retain their underlying voicing before prevocalic /v/, which suggests that Russian /v/ is transparent to voice assimilation. But without evidence of voice assimilation before 'true' sonorant consonants, the claim of general sonorant transparency becomes weak. Hayes' theory that [v] is underlyingly /w/ explains why obstruents retain their underlying voicing before prevocalic [v]. However, it does not immediately follow that voice assimilation before [v] is a case of *propagation* of voicing through a *sonorant*. The crucial difference between /v/ and the other sonorants is the fact that /v/ always surfaces as a fricative in Standard Russian. To ensure this fact, Hayes proposes a rule of 'W Strengthening'. The result of strengthening of /w/ is a fricative [v], which can trigger voice assimilation, like any other fricative in Russian.

Another striking result of this study is that presonorant stops in obstruent–sonorant–obstruent clusters are prone to variation in proportion of voicing to closure duration. This variation is greater than in single word-internal intervocalic stops. Ringen & Kulikov (2012) report that 97·5% of underlying voiced stops in this position in Russian are pronounced with voicing during the entire closure, and that all underlying voiceless stops in the sample have voiceless closure.[11] In contrast, some presonorant obstruents in this study show variation in voicing ratio, but I argue that such variation cannot be interpreted as voice assimilation through a sonorant.

The results indicate that this variation was not triggered by the rightmost obstruent in a cluster. It was found not only in voiceless C_1 stops before voiced C_2 obstruents and in voiced C_1 stops before voiceless C_2 obstruents (a scenario that might indicate voice assimilation), but also in voiceless C_1 stops before voiceless C_2 stops and in voiced C_1 stops before voiced C_2 obstruents. Crucially, 23% of all presonorant underlying /d/'s in clusters with a voiced C_2 had incomplete voicing during closure; 6% of all presonorant underlying /t/'s in clusters with a voiceless C_2 were fully voiced. Apparently, voice assimilation is an impossible scenario in these cases and gradient changes in voicing duration can best be described as random phonetic variation in production of voicing.

Variation in acoustic parameters of presonorant C_1 stops differed across the speaker population. Speakers had different tendencies for devoicing and voicing before a sonorant. Some speakers never produced voicing or

[11] They typically have a short voicing tail into closure ($M = 22{\cdot}5$ ms, SD = 11·1), which is 24% of mean closure duration.

devoicing, even in fast speech, while others produced some underlying voiced tokens with incomplete voicing.

It is clear that more research is needed to uncover the sources of such variation. But any discussion of variable voicing should consider at least some of the following factors. One possible reason for variation in voicing duration is phonetic context. Note that such variation occurs in presonorant obstruents, and that previous studies have shown that this context can affect voicing duration. Shorter prevoicing is found in word-initial stops for Dutch (van Alphen & Smits 2004) and Russian (Kulikov 2012). Closure voicing in voiced stops is shorter, and incomplete closure voicing occurs more often in presonorant position in English (Docherty 1992) and in Russian (Kulikov 2012). Therefore, shorter duration of closure voicing in obstruent–sonorant–obstruent clusters is consistent with this pattern, and may be a natural outcome of the presonorant phonetic context in which voiced obstruents are produced.

Speech tempo might also affect production of voicing. Variation in voicing duration in obstruents in prepositions was found more often in fast speech. The reasons for more variable production of voicing in fast speech can be found in the articulatory implementation of voicing. Production of voicing during closure crucially depends on the timing of two events: the end of stop closure and the onset/offset of vocal fold vibration. Controlling the timing of articulatory gestures is harder in fast speech than in slow speech; more 'noise' in production is therefore expected in fast speech.

It is possible that relationships between alternations found in obstruent–sonorant–obstruent clusters and speaking rate are a legitimate result of a trade-off between the speaking rate and the complexity of syllable structure (see Chitoran & Cohn 2009 for discussion). Chitoran & Cohn suggest that syllable complexity correlates with speaking rate. Syllabic structure is preserved at slow rate and simplified at fast rate. The results of this study support this hypothesis. Speakers used different repair strategies (feature sharing, metathesis, deletion) to produce simpler syllable structures in 14% of obstruent–sonorant–obstruent clusters in the fast rate condition. Changes in voicing duration in such clusters, sometimes interpreted as a voice assimilation through a sonorant in Russian, are not even the most numerous cases of modification. Nasalisation and sonorant devoicing occurred as often as changes in voicing duration.

Another possible source of variation might be dialect. An anonymous reviewer has suggested that sonorant transparency may be present in some dialects of Russian, but absent in other dialects. This is plausible, as Russian dialect phonology does have variation in the application of phonological rules (see Crosswhite 2000 for a phonological analysis of vowel reduction in Russian). Variation in voicing in obstruent–sonorant–obstruent clusters, however, cannot be unequivocally attributed to dialect variation. Although Roman Jakobson always admitted that his idiolect deviated from Standard Russian in certain ways, we do not know whether those differences were dialectal, as we do not have the necessary recordings of his speech. In addition, comprehensive descriptions of Russian dialects (Avanesov & Bromlej 1986) do not report cases of sonorant transparency in regional varieties of Russian. It is not clear at this point which Russian dialects might have it. Individual variation, however, can probably explain some aspects of claims about sonorant transparency. Recall that three speakers in this study had more tokens with variation in voicing than other speakers. Although these tokens do not represent a pattern of voice assimilation, this example demonstrates that some speakers of Russian may occasionally pronounce obstruent–sonorant–obstruent clusters with partially devoiced C_1 obstruents in casual speech.

I conclude that the paper presents experimental acoustic evidence that obstruents in clusters in Russian do not assimilate in voicing when a sonorant consonant intervenes. The results are not consistent with the current claims about 'sonorant transparency' in Russian as a phonological fast speech rule. Further research, involving a wide variety of speakers and lexical items, will help us understand the source of greater variation in closure voicing observed in some tokens in long clusters, and pinpoint factors that might explain such variation.

Appendix: Tables showing results of acoustic measurements

		/d/		/t/	
cluster	C_2	slow	fast	slow	fast
C_1–son–C_2	voiced	50·9 (13)	46·4 (16)	17·2 (8)	17·0 (5)
	voiceless	51·5 (12)	48·5 (14)	18·2 (7)	19·7 (8)
	total	51·3 (13)	47·5 (15)	17·7 (8)	18·4 (7)
C_1–C_2	voiced	54·4 (9)	42·8 (8)	51·4 (10)	40·3 (8)
	voiceless	18·0 (7)	19·4 (4)	16·0 (6)	17·2 (7)
	total	36·2 (16)	31·1 (15)	33·7 (16)	28·8 (14)

Table V

Means (ms) and standard deviations (in parentheses) of voicing duration in underlying voiced and voiceless C_1 stops in clusters with and without an intervening sonorant.

		/d/		/t/	
cluster	C_2	slow	fast	slow	fast
C_1–son–C_2	voiced	57·8 (13)	54·9 (14)	64·7 (13)	50·3 (16)
	voiceless	64·4 (14)	57·2 (14)	75·3 (17)	58·0 (15)
	total	61·1 (14)	56·1 (14)	70·0 (15)	54·2 (16)
C_1–C_2	voiced	55·4 (9)	43·1 (8)	54·7 (11)	42·5 (6)
	voiceless	55·5 (11)	44·2 (12)	62·3 (7)	48·4 (8)
	total	55·5 (10)	43·7 (10)	58·5 (10)	45·5 (7)

Table VI

Means (ms) and standard deviations (in parentheses) of closure duration of underlying voiced and voiceless C_1 stops in clusters with and without an intervening sonorant.

		/d/		/t/	
cluster	C_2	slow	fast	slow	fast
C_1–son–C_2	voiced	62·6 (17)	53·7 (15)	78·1 (13)	72·2 (15)
	voiceless	64·6 (21)	52·9 (15)	75·7 (17)	69·7 (21)
	total	63·6 (19)	53·3 (14)	76·9 (18)	70·9 (19)
C_1–C_2	voiced	70·8 (17)	56·8 (14)	78·1 (13)	66·8 (16)
	voiceless	65·7 (18)	55·4 (13)	77·2 (11)	66·1 (14)
	total	68·2 (17)	56·1 (13)	77·6 (15)	66·4 (15)

Table VII

Means (ms) and standard deviations (in parentheses) of duration of a vowel preceding underlying voiced and voiceless C_1 stops in clusters with and without an intervening sonorant.

cluster	C_2	/d/	/t/
C_1–son–C_2	voiced	507 (86)	512 (74)
	voiceless	509 (92)	514 (87)
C_1–C_2	voiced	544 (81)	526 (83)
	voiceless	536 (95)	526 (87)
	total	524 (89)	519 (83)

Table VIII

Means (Hz) and standard deviations (in parentheses) of F1 on vowels preceding underlying voiced and voiceless C_1 stops.

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