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Testing *Licensing by Cue*

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Abstract

This paper tests the hypothesis *Licensing by Cue* (Steriade 1997) applying it to the distribution of Russian plain-palatalized contrast in coronal stops /t/ vs. /t^j/ in two environments (V_C, V_#). The hypothesis holds that the maintenance of the contrast should correspond to more acoustic information in the signal and higher identification rate, and that its neutralization should be accompanied by fewer cues and lower recognition of the segments. The results of acoustic and perceptual experiments do not fully support the hypothesis: while the relative acoustic and perceptual salience of the contrast before three consonants (_#k, _#n, _#s) correlates with within-word neutralization patterns, the lack of neutralization after three vowels (a_, u_, and i_) does not follow from the acoustic and perceptual results. The findings suggest that acoustic and perceptual factors play a certain role in maintenance and neutralization of phonological contrasts, however, the mapping between acoustics and phonology is not direct.

1 Introduction

Recent work in phonology has revived interest in phonetic factors as a source of explanation for various phonological patterns (Flemming 1995, Jun 1995, Hamilton 1996, Silverman 1997, Steriade 1997, etc.). One of the directions taken in these works is to account for phonemic neutralization, deriving it from acoustic cues (Licensing by Cue: Steriade 1997). In this view phonological contrasts are neutralized in environments that are poor in terms of phonetic information and are licensed in positions that are high on a scale of perceptibility. This approach argues against the traditional view that treats phonemic neutralization a result of phonological syllable structure constraints. The hypothesis of Licensing by Cue makes straightforward predictions about neutralization environments that can be experimentally verified.

The goal of this paper is to test the licensing by cue, or phonetic hypothesis by examining the role of acoustic cues in the complex distribution of Russian plain and palatalized coronal stops. I will investigate the acoustic and perceptual parameters distinguishing the contrast /t/ vs. /t^j/ in two environments and will show that while the hypothesis makes correct predictions about neutralization of the contrast in one of them, it does not account for the lack of neutralization in the other context. I propose a revised approach to neutralization as an output of the interaction of both external (phonetic) and internal (phonological) factors.

The paper is organized as follows. Section 1 presents the data, the distribution of the contrast /t/-/t^j/, and outlines the main theoretical assumptions and predictions. In Sections 2 and 3 I test the predictions by means of acoustics and perception experiments. Section 4 discusses the theoretical implications of the findings.

2 Licensing by Cue and Russian palatalization

2.1 Licensing by Cue

In this work I will test the hypothesis of *Licensing by Cue,* developed in recent work by Steriade (1997) (cf. Flemming 1995, Hamilton 1996, Kochetov 1999, among others). The concept of a phonetic cue comes from experimental work on speech perception, where a "cue" is treated as "a term of convenience, useful for the purpose of referring to any piece of signal that has been found by experiment to have an effect on perception" (Liberman 1996:22).

The key idea of Licensing by Cue is that the distribution of a phonological contrast is sensitive to the amount of acoustic information available in a given environment. Environments that contain fewer or less salient acoustic cues are lower on a scale of perceptibility, and thus are more likely to be neutralized.[1] The relation between the phonetic cues and phonological contrast can be presented schematically as implicational relations, as in Figure 1. If an acoustic signal contains more information about the contrast (e.g., cues available in formant transitions, burst release, nasal murmur etc.), the contrast is likely to be preserved, or licensed. If less acoustic information is present, the contrast is more likely to be neutralized. Also, a contrast that is distinguished by fewer and less salient cues is more prone to neutralization than a distinction supported by a robust set of cues.

Acoustic Signal		*Phonological Grammar*
Information	⇒	Contrast
A more		licensed
B less	⇒	neutralized

Figure 1
Schematic relations between phonetics (acoustic signal) and phonology (grammar) in neutralization of a contrast

Since cues to a contrast and their salience are determined experimentally, we should expect that maintenance or neutralization of a contrast will correlate with relative identification rate of the contrast by listeners under various conditions. Imagine two environments A and B (Table 1). If environment A provides more acoustic information to a contrast between two segments /x/ and /y/, the identification of the contrast by listeners is likely to be high, and, as a result, the contrast would be preserved. On the other hand, if environment B provides less acoustic information to the contrast, the identification rate of /x/ vs. /y/ would tend to be lower and the contrast is more likely to be neutralized. Note

[1] Note that neutralization is understood here as a general absence of contrast between two segments in a given phonotactic environment, not necessarily neutralization exemplified by phonological alternations (cf. Steriade 1997).

that it is possible that a contrast is maintained in both contexts. However, if the contrast is neutralized in environment A, it has to be also neutralized in environment B. Also, in the absence of categorical neutralization in A and B, we are likely to find some frequency asymmetries: the contrast in A should be more frequent than the contrast in B or neutralization will be found in isolated lexical items.

Environment	*Information*	*Identification*	*Contrast* /x/ vs. /y/
A	more	high	yes
B	less	low	no

Table 1. Acoustic (information) and perceptual (identification) factors and the distribution of a hypothetical contrast /x/ vs. /y/ in environments A and B

In the next section I turn to the data from Russian that will provide a testing ground for the outlined paradigm. The question to be considered is whether the distribution of palatalized /t^j/ depend on the quality of the following and preceding segment.

2.2 The contrast /t/ vs. /t^j/

Russian palatalized coronals are the least constrained among palatalized segments (Table 2). Unlike palatalized velars they occur post-vocalically (syllable coda) and unlike palatalized labials, they can be contrastive preconsonantally. Yet, the details of the distribution of palatalized coronals are rather complex and have not been straightforwardly accounted for (Kiparsky 1979). Note that the corresponding plain stops are not limited in their occurrence.

	Plain	*Palatalized*		
Environment	all	coronal	labial	velar
__V	yes	yes	yes	yes
__#	yes	yes	yes	no
__C	yes	yes/no	no	no

Table 2. Distribution of Russian plain and palatalized consonants; yes = unrestricted; yes/no = restricted, no = prohibited (based on Avanesov (1972)

In this section we will examine the phonemic contrast between coronal stops /t/ and /t^j/ in two coda contexts: before consonants and after vowels. Examples and frequencies are drawn from a corpus of Russian words with post-vocalic /t^j/ in final and preconsonantal positions, based on Zalizniak (1977), Townsend (1982), and complemented by the author. The corpus contains 109 words with final /t^j/. Words with /t^j/ before consonants are substantially less frequent (31 items).

2.2.1 Following consonant

The contrast before following velars (particularly /k/) is quite common (1).

(1)	Ka[t^jk]a	*Kate*, familiar	ka[tk]a	*pail*
	ba[t^jk]a	*dad*, familiar	lopa[tk]a	*paddle*
	d'a[t^jk]a	*uncle*, familiar	vz'a[tk]a	*bribe*
	re[t^jk]a	*radish*	re[tk]o	*rare*

Most of these words are diminutives and nicknames derived from nouns of the 2nd declension by the suffix *-k-* (e.g., *Ka*[t^j]*-a* --> *Ka*[t^j]*-k-a*). Interestingly, the pattern does not hold for nouns of the 3rd declension: adding the suffix *-k* leads to depalatalization of /t^j/ (2).

(2)	ni[t^j]	*thread*	ni[tk]a	*thread,* dimin.
	ma[t^j]	*mother*	ma[tk]a	*womb*
	žu[t^j]	*horror*	žu[tk]ij	*horrible*

The palatalized /t^j/ (and its voiced counterpart /d^j/) is attested before labials (3). The sequences [d^jb], [t^jm], [d^jm], are contrastive with the sequences [db], [tm], [dm], however, the latter occur only across prefix-stem boundaries.

(3)	sva[d^jb]a	*wedding*	po[db]adrivat'	*to cheer up*
	po[t^jm]a	*dusk*	o[tm]yt'	*to wash off*
	ve[d^jm]a	*witch*	po[dm]oga	*help*
	se[d^jm]oj	*seventh*	po[dm]ostki	*scaffold*

The contrast between /t/ and /t^j/ is completely neutralized before coronals (e.g., before /n/ and /s/): only plain /t/ is allowed before these consonants. When words with a final palatalized /t^j/ combine with derivational affixes (e.g., high frequency suffixes *-n, -sk,* and *-stv*) or other stems beginning with a coronal, the underlying palatalized /t^j/ surfaces as a plain /t/ (4a). There are no exceptions to this constraint. Plain /t/ does not undergo any changes (4b).

(4)	a.	pu[t^j]	*way*	pu[tn]yj	*appropriate*
		p'a[t^j]	*five*	p'a[tn]adcat'	*fifteen*
		plo[t^j]	*flesh*	plo[ts]kij	*carnal*
		p'a[t^j]	*five*	p'a[ts]ot	*fifty*
		my[t^j]	*to wash*	my[ts]a	*to wash oneself*
	b.	po[t]	*sweat*	po[tn]yj	*sweaty*
		a[t]	*hell*	a[ts]kij	*hellish*

To summarize, while the plain /t/ is not sensitive to the following consonant, occurring before a large number of consonants, the palatalized /t^j/ is severely restricted. It is allowed only before labials and velars and disallowed before coronals.

Applying the reasoning of Licensing by Cue, neutralization of the plain-palatalized contrast should be favoured in the contexts that provide less information about the contrast and preserved in the environments that host a more salient set of cues (Table 3). Since the /t/ vs. /t^j/ contrast is preserved before /k/ and neutralized before /n/ and /s/, we should expect to find that there is more acoustic information distinguishing the contrast in the first context compared to the other two environments. We should also find that under some conditions listeners perceive the contrast better before /k/ than before /n/ and /s/.

Environment	*Information*	*Identification*	*Contrast*
__k	more?	high?	yes
__n	less?	low?	no
__s	less?	low?	no

Table 3. Predictions about acoustic and perception based on the distribution of /t/ vs. /t^j/ contrast in three consonantal contexts

All the above-mentioned constraints apply only within words. Nothing prohibits /t^j/ before any consonant of a following word or particle (5). This fact will allow us to examine the full range of clusters and to determine their acoustic and perceptual differences.

(5)	ma[t^j#n]ačal'nika	ma[t#n]ačal'nika
	boss's mother	*boss's foul language*
	ma[t^j#s]otrudnika	ma[t#s]otrudnika
	colleague's mother	*colleague's foul language*
	ma[t^j#k]onduktora	ma[t#k]onduktora
	conductor's mother	*conductor's foul language*

2.2.2 Preceding vowel

Plain and palatalized coronal stops contrast after all vowels, regardless of the position, final or medial (6). Our analysis, however, will be limited to the final environment after /a/, /u/, and /i/.

(6) a. Final coda:

m[at^j]	*mother*	m[at]	*mat*
d[ut^j]	*to blow*	d[ut]	*blown*
x[ot^j]	*though*	x[ot]	*walk*
b[it^j]	*to beat*	b[it]	*beaten*
p[et^j]	*to sing*	p[et]	*sung*

b. Preconsonantal coda:

K[at^j]ka	*Katya*, familiar	k[at]ka	*pail*
tj[ut^j]kat's'a	*to baby talk*	b[ut]ka	*booth*
Vol[ot^j]ka	*Volodya*, familiar	l[ot]ka	*boat*
V[it^j]ka	*Vitya*, familiar	n[it]ka	*thread*
r[et^j]ka	*radish*	r[et]ko	*rarely*

We see that there are no distributional restrictions on the contrast depending on the quality of the following vowel. Interestingly, the frequency of [i] before /t^j/ in the corpus (final environment) is higher than average in the language (28% vs. 18%) (Kucera & Monroe 1968:33).

Since the /t/ vs. /t^j/ contrast is preserved after all three vowels, we should expect to find that the three environments have sufficient acoustic cues ("more information") and do not differ significantly with respect to the amount of this acoustic information (Table 4). Or if they do, these differences should be irrelevant for a listener ("high identification").

Environment	*Information*	*Identification*	*Contrast*
a__	more?	high?	yes
u__	more?	high?	yes
i__	more?	high?	yes

Table 4. Predictions about acoustics and perception based on the distribution of /t/ vs. /t^j/ contrast in three vocalic contexts

To summarize, the distinction between the plain and palatalized coronal stops is maintained before some consonants (e.g., /k/, /b/, /m/) and neutralized before others (e.g., /n/ or /s/). In the context of the latter consonants we find only plain stops. The occurrence of the plain-palatalized contrast is not conditioned by preceding vowels.

2.3 Acoustic cues to /t/ vs. /t^j/

Before we proceed to the experiments, it is important to introduce the cues to the plain-palatalized distinction. Acoustic and perceptual correlates of /t/ and /t^j/ were examined in Halle (1959), Bolla (1981), Bondarko (1981), among others, and recently by Kochetov (2001). The latter study focused on these consonants within words in coda positions (final and preconsonantal). In both cases the preceding vowel was /a/ and the following consonant in the preconsonantal position was /k/. Acoustic analysis determined that in both positions the two consonants differed in the following parameters (Table 5): duration of closure and burst, as well as the quality of VC transition and burst. Both stops were consistently released finally and before /k/.

Segment (Coda position)	*VC transition*		*Closure*	*Burst*	
	Slope	F2 ending frequency (Hz)	Silence duration (ms)	Noise spectrum	Noise duration (ms)
/t/	rising/level	mid (1450)	longer (115/59)	diffuse flat	shorter (81/26)
/t^j/	rising	high (2000)	shorter (71/43)	less diffuse rising	longer (115/51)

Table 5. Acoustic parameters associated with the contrast /t/-/t^j/ in coda.
The second duration value is given for preconsonantal position

Perceptual experiments that involved identification of the two consonants after one vowel, /a/, revealed that of these parameters, only VC transition and burst were perceptually relevant in the identification of the two phonemes (Kochetov 2001). The two environments, final and preconsonantal, differed in the relevant importance of cues to the contrast: VC transition was found to be more important for the final /t/ vs. /t^j/ contrast, while burst was a major cue to the contrast in preconsonantal position.

As the distribution facts indicate, the plain-palatalazed contrast is sensitive to the nature of the following consonant. The questions that are central to the current study are as follows. What makes /t/ and /t^j/ contrastive in some coda positions and neutralized in others? Is the neutralization before /n/ and /s/ due to the absence of some acoustic information? I also found that /t/ vs. /t^j/ distinction is not affected by the preceding vowel. Is it because there are no acoustic differences between the environments or they are perceptually irrelevant? These questions will be addressed in the following sections.

3 The contrast /t^j/ vs. /t/ before consonants

3.1 /t^j/ vs. /t/ before /k/, /n/, and /s/: Acoustics

The goal of Experiment 1 is to determine how the contrast between plain and palatalized /t^j/ differs acoustically depending on the quality of the following consonant. We will look at three preconsonantal environments: before the velar stop /k/ and the coronals /n/ and /s/. As mentioned above, /t^j/ can be contrastive with /t/ within words before /k/, but not before /n/ and /s/. However, all three clusters are found across word boundaries. In this experiment I consider the word-boundary clusters, assuming that their acoustics is by and large similar to that of clusters within words. The prediction made by *Licensing by Cue* is that the first environment (__k) has more acoustic information distinguishing /t/ and /t^j/ than the other two contexts (__n and __s).

3.1.1 Materials, procedure, and analysis

Six native speakers of Russian, three males (Speakers 1, 4, 6) and three females (Speakers 2, 3, 5), participated in the experiment.[2] Test words presented to the speakers consisted of (near-)minimal word pairs containing word-final phonemes /t/ and /t^j/ preceded by /a/ and followed by word-initial consonants /k/, /n/, and /s/ (Table 6). For all phrases stress was held constant: the first syllable of the second word was pre-tonal and had the same vowel, unstressed [a].

Three repetitions of the stimuli were randomized and embedded in a carrier phrase Skažite ___ ("Say __"). The sentences, interspersed with unrelated filler words, were presented in lists in Russian orthography, which exhibits the contrast. Speakers were recorded in a quiet room using a Marantz tape-recorder. Before recording, speakers practiced reading a few randomly chosen test sentences to familiarize themselves with the materials. Materials were read at a comfortable speed throughout the recording session.

Recorded speech was digitized at a sampling rate of 11 kHz with 16-bit resolution, and stored as files to be processed by Signalyze 3.2 (http://www.agoralang.com/signalyze.html).

The total number of target words obtained was 216 (12 words × 3 repetitions × 6 speakers). Only the second production was considered, for a total of 72 tokens. Several tokens from Speaker 4, with a short pause between the /t^j/ and /s/, were discarded. Each cluster was examined for an audible burst release on the basis of both wide-band spectrograms and waveforms, with additional reference to zero-crossing. The signal was considered to have a burst if a spectrogram indicated a noise of duration of 5 ms or more. Waveforms and zero crossing rates were used for additional reference. No duration measurements were taken.

Significance of the results (averaged by speaker) was tested by analysis of variance (ANOVA). The design involved two Between items, Plain-Palatalized Consonant (/t/ or /t^j/) and Following Consonant (/k/, /n/, and /s/) and one dependent variable (the rate of burst presence; 0.00 = burst absent, 1.00 = burst present). In addition to the ANOVAs, if an analysis showed interaction between factors I ran post-hoc Newman-Keuls tests in order to determine the source of the interaction. In order to determine whether the results differed from speaker to speaker, I ran an ANOVA with one between-item factors, Speaker (six levels) and one dependent variable (the rate of burst presence).

[2] The subjects are all speakers of Standard Russian in its several territorial variants: Speaker 1 (Lipetsk/Moscow), Speaker 2 (Moscow), Speaker 3 (Moscow), Speaker 4 (Arkhangelsk/Moscow), Speaker 5 (Vilnius, Lithuania), and Speaker 6 (Perm'). Speakers 5 and 6 (the author) are graduate students in the University of Toronto Linguistics Department.

	/t/	/t^j/
1	ma[t#k]onduktora *conductor's foul language*	ma[t^j#k]onduktora *conductor's mother*
2	ma[t#n]ačal'nika *boss's foul language*	ma[t^j#n]ačal'nika *boss's mother*
3	ma[t#s]otrudnika *colleague's foul language*	ma[t^j#s]otrudnika *colleague's mother*
4	sn'a[t#k] obedu *taken off for lunch*	sn'a[t^j#k] obedu *to take off for lunch*
5	sn'a[t#n]a plёnku *taken a picture*	sn'a[t^j#n]a plёnku *to take a picture*
6	sn'a[t#s]o stenda *taken off the stand*	sn'a[t^j#s]o stenda *to take off the stand*
7	bra[t#k]ogda-to *taken sometimes*	bra[t^j#k]ogda-to *to take sometimes*
8	bra[t#n]adolgo *taken for long time*	bra[t^j#n]adolgo *to take for long time*
9	bra[t#s]obrals'a *brother is going to*	bra[t^j#s]obrals'a *going to take*
10	sva[t#k]assira *cashier's matchmaker*	zva[t^j#k]assira *to call a cashier*
11	sva[t#n]ačal'nika *boss's matchmaker*	zva[t^j#n]ačal'nika *to call the boss*
12	sva[t#s]apёra *sapper's matchmaker*	zva[t^j#s]apёra *to call a sapper*
13	izm'a[t#k]ogda-to *wrinkled some time ago*	izm'a[t^j#k]ogda-to *to wrinkle some time ago*
14	izm'a[t#n]ar'ad *wrinkled attire*	izm'a[t^j#n]ar'ad *to wrinkle attire*
15	izm'a[t#s]ovsem *wrinkled entirely*	izm'a[t^j#s]ovsem *to wrinkle entirely*
16	op'a[t#k]orzinu *a basket of mushrooms*	op'a[t^j#k]orzinu *a basket again*
17	op'a[t#n]asobirali *picked up mushrooms*	op'a[t^j#n]asobirali *picked up again*
18	op'a[t#s]obrali *picked up mushrooms*	op'a[t^j#s]obrali *picked up again*

Table 6. (Near)-minimal pairs contrasting /t/ and /t^j/ used in Experiment 1

3.1.2 Results and discussion

Table 7 presents the results, means and standard deviations for the two segments in three consonant contexts.

Environment	*t*	*t^j^*
__k	0.97 (0.07)	0.97 (0.07)
__n	0.12 (0.19)	0.40 (0.34)
__s	0.17 (0.26)	0.28 (0.44)

Table 7. Mean and standard deviation values for presence or absence of burst in three preconsonantal contexts; 1 = burst is always present, 0 = burst is always absent

The ANOVA test revealed that Following Consonant was highly significant [$F(1,15) = 30.28$, $p < 0.001$] (Table 8). The quality of the burst (plain or palatalized) did not play a role [$F(1,15) = 2.16$, $p > 0.15$]. In the case of /n/ and /s/ the standard deviations were higher than burst presence values. This was due to some inconsistency of some speakers in their release (discussed below).

Source of Variance	*DF*	*F*	*p*
Burst (plain-palatalized)	1, 30	2.161	0.152
Following C (k, n, s)	2, 30	**30.282**	**0.000**
Burst * Following C	2, 30	0.848	0.438

Table 8. Burst release before consonants

The Newman-Keuls test showed significant differences between the environments before /k/ vs. before /n/ and /s/ (both $p < 0.001$). The two latter contexts were not significantly different from one another.

It should be noted that in a number of cases the release of the stop was very weak (low amplitude noise of duration of less than 10 ms), particularly, before /s/. It is unlikely such a signal could be perceived by a listener. Another important issue is that in the case of /s/, the stops were likely to be released, however, their burst was masked by a much stronger strident noise of the following /s/. This case was exactly the opposite of the release before /k/, where the burst was followed by silence of the closure of /k/ (about 60 ms), giving a listener additional time for processing the burst.

There was some variation among speakers, particularly before /n/ and /s/. Thus, Speaker 3 consistently released /t^j/ before /n/, while Speaker 5 released both /t/ and /t^j/ before /s/ in 67% of the cases. The ANOVA results revealed, however, that the factor of Speaker was not significant [$F(5, 24) = 0.116$; $p > 0.98$].

As illustrated in Figure 2, both /t/ and /t^j/ were almost always released before /k/ (97%). This confirms the results for the same environment within words in Kochetov (2001). Release was much less frequent before /n/ and /s/, particularly for the plain /t/.

Thus, the environments before /k/, /n/, and /s/ differ only in one respect: the presence or absence of burst release. While the environment before /k/ allows for a salient burst release, the other two contexts are less favourable for this acoustic component.[3] As was

[3] A pilot study (one subject) determined that /t^j/ was audibly released before labials /p/, /m/, and /v/. The noise of following voiceless fricatives /f/ and /x/ masked the release of /t^j/. No release was found before coronals /n/, /s/, /ts/, and /Σ/. The results for /l/ and /r/ were not clear.

discussed above (Section 2.3) burst is one of the cues to plain-palatalized contrast before consonants. This result confirms our prediction that the first context differs from the two other environments in the amount of acoustic information (Table 9).

Having found that the contexts differ acoustically, we still need to show whether this acoustic difference is relevant to the identification of the contrast. This will be determined by a perception experiment.

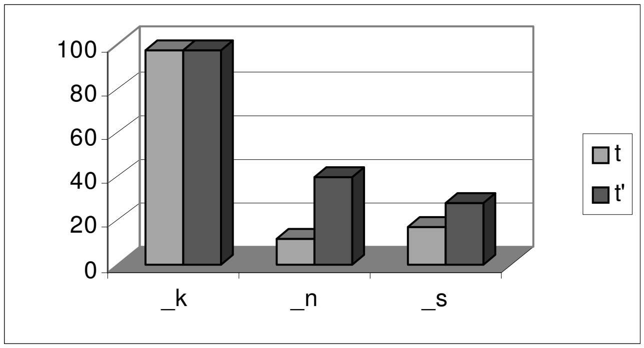

Figure 2
Presence of burst of /t/ and /t^j/ in three preconsonantal environments (across word boundaries).

Environment	*Information*	*Identification*	*Contrast*
__k	**more**	**high?**	yes
__n	**less**	**low?**	no
__s	**less**	**low?**	no

Table 9. Acoustic information, identification, and contrast in three consonantal environments

3.2 /t^j/ vs. /t/ before /k/, /n/, and /s/: Perception

Experiment 2 investigates the perception of the plain-palatalized contrast before three consonants across word boundaries. This is tested under two conditions, with complete stimuli and those with reverted palatalized transition. Given the distribution of the contrast before consonants and the results of our acoustic analysis, we expect to find that under certain conditions the identification of /t/ vs. /t^j/ should be better before /k/ than before /n/ and /s/.

3.2.1 Materials, procedure, and analysis

The materials were minimal pairs in phrases (Table 10) pronounced by Speaker 1.[4] The stimuli contained three conditions: plain /t/, palatalized /t^j/, and /t^j/ with the transition reversed from palatalized to plain. This was done to determine the net contribution of the burst to signaling the phonemic distinction. The stimuli were presented to listeners in random order with a two second response-to-stimulus interval, using the program PsyScope (Cohen, MacWhinney, Flatt, and Provost 1993). Listeners pressed one key if they heard a plain /t/ and the other key if they heard /t^j/. Response times (RT) were also measured. All of the stimuli were presented twice. The mean identification rates (proportion correct) were based on the averages of two tokens per word from twelve listeners. The total of 864 tokens (36 stimuli × 1 speaker × 2 repetitions × 12 listeners) were averaged by subject and served as an input to ANOVA with 2 within subjects factors: Consonant (/t/, /t^j/, and /t^j/ with plain transition), and Following Consonant (/k/, /n/, and /s/). The response time was analyzed similarly. Only positive answers were considered.

	/t/	/t^j/
1	ma[t#k]onduktora	ma[t^j#k]onduktora
	conductor's foul language	*conductor's mother*
2	ma[t#n]a◊al'nika	ma[t^j#n]a◊al'nika
	boss's foul language	*boss's mother*
3	ma[t#s]otrudnika	ma[t^j#s]otrudnika
	collegue's foul language	*collegue's mother*
4	sn'a[t#k] obedu	sn'a[t^j#k] obedu
	taken off for lunch	*to take off for lunch*
5	sn'a[t#n]a plënku	sn'a[t^j#n]a plënku
	taken a picture	*to take a picture*
6	sn'a[t#s]o stenda	sn'a[t^j#s]o stenda
	taken off the stand	*to take off the stand*

Table 10. Minimal pairs contrasting /t/ and /t^j/ used in Experiment 2

3.2.2 Results and discussion

Mean identification scores and response time results are presented in Table 11.[5]

[4] The experiment was limited to one speaker due to time constraints. This particular speaker, a former university instructor, was evaluated by two native Russian speakers as speaking "Standard Russian" without a regional accent.

[5] Mean response time (RT) values of negative responses were 462 (251) for __*n* and 577 (316) for __*s*.

Identification	*/t/*	*/t^j/*	*/t^j/ transition reversed*
__k	1.000 (0.000)	0.967 (0.079)	0.867 (0.192)
__n	0.983 (0.058)	0.983 (0.058)	0.050 (0.117)
__s	0.833 (0.227)	1.000 (0.000)	0.208 (0.257)
Response time			
__k	561 (217)	594 (335)	667 (460)
__n	620 (304)	550 (203)	830 (442)
__s	730 (286)	410 (238)	938 (501)

Table 11. Means and standard deviations for identification of the contrast (out of 1) and response time (ms)

Both factors, Cues and Following Consonant were highly significant: [F(2, 22) = 158.92; p < 0.001] and [F(2, 22) = 64.51; p < 0.001]. The interaction of the factors was also significant [F(4, 44) = 33.21; p < 0.001] (Table 12). The Newman-Keuls test showed that the significant result was due to the differences between the environment that retained the burst of /t^j/ (__k) and those that did not, __n (p < 0.001) and __s (p < 0.015). Also /t/ and /t^j/ without transition were significantly different before /n/ (both p < 0.001) and before /s/ (both p < 0.001).

Identification	*DF*	*F*	*p*
Consonant (/t/, /t^j/, /t^j/ with plain transition)	2, 22	**158.915**	**0.000**
Following C (k, n, s)	2, 22	**64.512**	**0.000**
Cues * Following C	4, 44	**33.214**	**0.000**
Response Time			
Consonant (/t/, /t^j/, /t^j/ with plain transition)	2, 22	**8.445**	**0.000**
Following C (k, n, s)	2, 22	0.743	0.478
Cues * Following C	4, 44	1.911	0.115

Table 12. Identification of the /t/-/t^j/ contrast and response time

The analysis of measures of response time indicated a significant difference in terms of Consonant [F(2, 22) = 8.45; p < 0.001]. Following Consonant was not a significant factor [F(2, 22) = 0.743; p < 0.478], although the mean values were lower before /k/ than before /n/ and /s/. No interaction was observed. A Scheffé test showed that the significant RT differences were only between /t^j/ and unreleased /t^j/ (p = 0.000). Plain /t/ did not differ significantly either from /t^j/ (p = 259), or from [t^j|] (p = 0.057).[6]

Figure 3 illustrates the results for identification. We can see that both /t/ and /t^j/ are reliably identified in all preconsonantal environments, due to the transition in the contexts

[6] Other post-hoc tests (Bonferroni-Dunn, Tukey-Kramer, and Student-Newman-Keuls) showed significant differences both between /t^j/ and [t^j|] and /t/ and [t^j|].

before /n/ and /s/. Response time is relatively low (except before /s/). The recognition of /t^j/ drops to almost zero before /n/ and /s/ when the vowel transition is changed to the plain one. Response time is the highest in these environments. This confirms lack of acoustic burst before these coronals. The presence of the burst before /k/, on the other hand, allows the segment to retain its salience on a fairly high level. Due to the absence of one cue, it takes listeners more time to recognize the phoneme. It is not clear what affected the identification and response time of plain /t/ before /s/.[7]

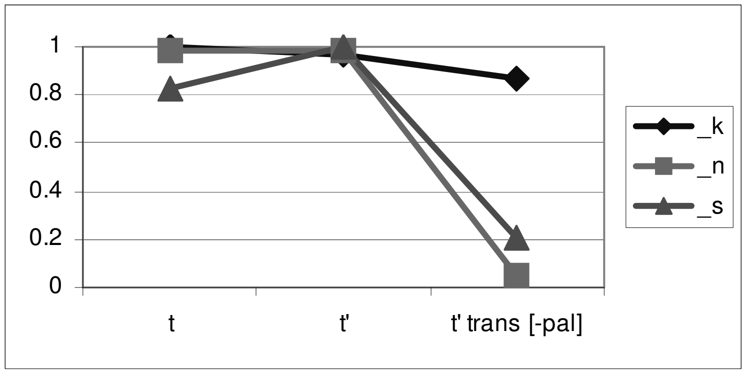

Figure 3
Perception of /t/, /t^j/, and /t^j/ with transition reversed
in preconsonantal environment across word boundaries.

The results of the experiment indicated that the nature of the following consonant affected the perception of /t/ and /t^j/. The contrast between /t/ and /t^j/ was more salient before /k/ than before /n/ or /s/. This is exactly what was predicted based on our hypothesis (Table 13): more acoustic information before /k/ leads to a higher identification rate, while few cues before /n/ and /s/ result in a significant drop in correct responses. The consequence of that is that the language maintains the plain-palatalized contrast in one environment and neutralizes it the others.

Environment	*Information*	*Identification*	*Contrast*
__k	more	**high**	**yes**
__n	less	**low**	**no**
__s	less	**low**	**no**

Table 13. Acoustic information, identification, and contrast
in three consonantal environments

In sum, the results of the experiment support the hypothesis of Licensing by Cue for the plain-palatalized contrast before consonants.

[7] It is possible that it is due its acoustic similarity with affricate /ts/.

4 The contrast /t^j/ vs. /t/ after vowels

The following experiments deal with the acoustic and perceptual characteristics of plain-palatalized contrast after three vowels in order to determine whether they affect the contrast of /t/ vs. /t^j/. Recall that, based on the hypothesis of Licensing by Cue, we should find that environments do not differ significantly from each other either in their acoustic or perceptual characteristics.

4.1 Acoustics

Experiment 1 will examine the acoustics of /t/ and /t^j/ before /a/, /u/ , and /i/.

4.1.1 Materials, procedure, and analysis

The procedure was the same as in Experiment 1. The test words were minimal pairs given that differ in the final /t/ and /t^j/ and the quality of the preceding vowel (Table 14). The total number of target words obtained was 108 (6 words × 3 repetitions × 6 speakers). Only the second production was considered, for a total of 36 tokens.

	/t/		/t^j/	
1.	ma[t]	*foul language*	ma[t^j]	*mother*
2.	du[t]	*blown*	du[t^j]	*to blow*
3.	bi[t]	*beaten*	bi[t^j]	*to beat*

Table 14. Minimal pairs contrasting /t/ and /t^j/ used in Experiment 3

The procedure involved measurements of formants F1, F2, and F3 at four points in time: at the offset of the vowel prior to the consonant closure (F2 ending), 30 ms before F2 ending, 60 ms before F2 ending, and 90 ms before F2 ending. Measurements were done using LPC (Linear Predictive Coding) spectra, with reference to wide-band spectrograms. Only F2, as the main correlate of the contrast (See Section 2.3), was used in the current analysis.

The collected data, averaged across speakers, were examined in separate analyses of variance for each point in time. The design involved two between-item factors, Vowel (/a/, /u/, and /i/) and Consonant (plain and palatalized) and a dependent variable (F2 value at a given point). To examine the consistency of results across speakers, I used an ANOVA with one between-item factors, Speaker (six levels) and one dependent variable (F2). To determine the differences between plain and palatalized F2 values of at each point for a given vowel I performed separate ANOVAs with between-item factor, Consonant, and dependent variable (F2 value at a given point for a given vowel). Post-hoc tests were run to determine the source of interaction.

4.1.2 Results and discussion

Means and standard deviations of the second formant values at four points in time for three vowels are given in Table 15. Differences between plain and palatalized F2 are shown at each point. Note that for all vowels the difference is minimal at the first point (105 Hz for /a/, 73 Hz for /u/, and 25 Hz for /i/) and is maximal at the last one (477 Hz, 394 Hz, and 434 Hz respectively). The dynamics of these differences, however, vary from vowel to vowel.

		F2 ending -90 ms	F2 ending -60 ms	F2 ending -30 ms	F2 ending (0 ms)
/a/	[at]	1230 (171)	1281 (137)	1362 (221)	1485 (218)
	[at^j]	1335 (88)	1559 (174)	1803 (179)	1962 (179)
	Difference	*105*	*278*	*442*	*477*
/u/	[ut]	1047 (220)	869 (102)	929 (98)	1178 (208)
	[ut^j]	974 (85)	932 (83)	1293 (232)	1572 (267)
	Difference	*73*	*63*	*364*	*394*
/i/	[it]	2419 (256)	2426 (188)	2405 (255)	1969 (185)
	[it^j]	2444 (263)	2503 (255)	2502 (285)	2403 (270)
	Difference	*25*	*77*	*97*	*434*

Table 15. Mean and standard deviation (in parenthesis) values for F2 (Hz)

Vowel was highly significant at all points in time ([$F(2, 22) = 180.412$; 272.982; 115.105; 39.551; $p < 0.001$] (Table 16). Consonant was significant at the last three points [$F(2, 22) = 6.289$; $p = 0.018$], [$F(2, 22) = 16.824$; $p = 0.000$], [$F(2, 22) = 33.928$; $p = 0.000$]. There was no interaction between Vowel and Consonant.

		F2 ending -90 ms	F2 ending -60 ms	F2 ending -30 ms	F2 ending (0 ms)
Vowel (/a/, /u/, /i/)	F	**180.412**	**272.982**	**115.105**	**39.551**
	p	**0.000**	**0.000**	**0.000**	**0.000**
Consonant (plain-palatalized)	F	0.090	**6.289**	**16.824**	**33.928**
	p	0.631	**0.018**	**0.000**	**0.000**
Vowel * Consonant	F	0.631	1.556	2.003	0.100
	p	0.539	0.227	0.147	0.905

Table 16. F2 at five points in time, final position (DF 2, 22)

The post-hoc Scheffé test showed that there were significant differences between all three vowels at all points in time (from $p = 0.007$ to $p < 0.001$). The factor of Speaker was not significant [$F(2, 22) = 0.182$; $p = 0.967$].

The results of separate ANOVA analyses for each vowel at each time are given in Table 17. As we see, the vowels differ with respect to when the transitions to /t/ and /t^j/ are significantly different. The difference between /t/ and /t^j/ is observed at three last points for /a/ ([$F(2,22) = 14.504$, $p = 0.003$], [$F(2,22) = 17.116$, $p = 0.002$], [F(2,22) =

9.448, p = 0.012]. It is found significant for two last points for /u/ [F(2,22) = 12.550, p = 0.005], [F(2,22) = 8.156, p = 0.017]. And, finally, for /i/ the difference is limited to the offset of the vowel [F(2,22) = 10.554, p = 0.009].

		F2 ending -90 ms	F2 ending -60 ms	F2 ending -30 ms	F2 ending (0 ms)
/a/	F p	1.800 0.209	**9.448** **0.012**	**14.504** **0.003**	**17.116** **0.002**
/u/	F p	0.571 0.467	1.374 0.268	**12.550** **0.005**	**8.156** **0.017**
/i/	F p	0.029 0.868	0.356 0.564	0.382 0.550	**10.554** **0.009**

Table 17. F2 at five points in time, final position (DF 2, 22 for all)

These results show the crucial differences of the three vowels with respect to the plain-palatalized contrast: /a/ has more acoustic information about the nature of the following vowel than /u/ and /i/. Among the last two, /u/ is a more informative context than /i/. Let's consider the F2 trajectories within the three vowels. Figure 4 plots mean F2 values of the vowel /a/ in the words *ma*[t] vs. *ma*[t^j] and Figure 5 shows the F2 trajectories of *du*[t] vs. *du*[t^j] and *bi*[t] vs. *bi*[t^j]. We can see from Figure 4 that the difference between plain and palatalized F2's within /a/ is observed during all the 90 ms, and is particularly obvious in the last 60 ms. At the onset of the consonant the palatalized F2 almost reaches 2000 Hz, while the plain F2 is close to 1400 Hz.

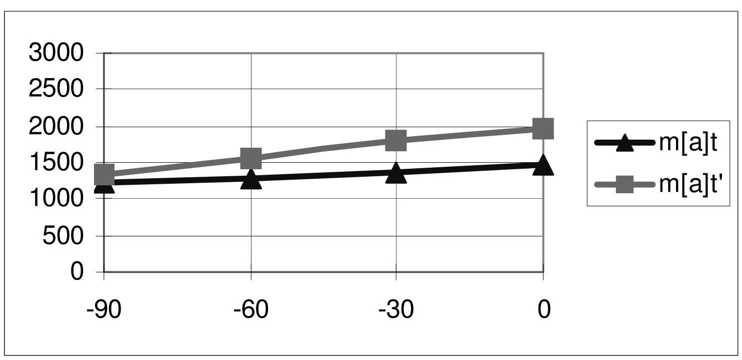

Figure 4
Mean F2 values for [a] in the words *ma[t]* and *ma[t^j]*.

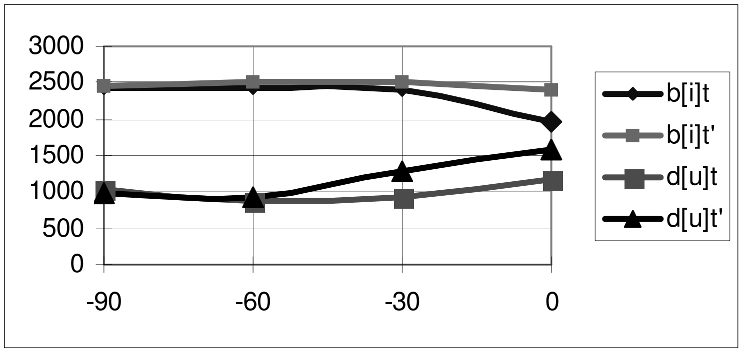

Figure 5
Mean F2 values at 4 points in time.

It can be seen from Figure 5 that in the contexts of high vowels the difference between the plain and palatalized F2 is more apparent only at about the last 50 ms for /u/ and at less than 30 ms for /i/. Since high back vowel /u/ is characterized by low F2, the formant stays level longer and does not attain the same ending value as in the case of /a/. Note that the values and trajectory of the palatalized F2 in /u/ is similar to the plain F2 in /a/. On the other hand, F2 of /i/ is characterized by the highest F2. Before /t^j/ it stays almost level at around 2500 Hz. The difference between /t/ and /t^j/ is due to lowering of F2 before the first consonant. F2, however, does not achieve the value of 1400 Hz we saw in the context of /a/. In general, the VC transitions to /t^j/ from /u/, and especially from /i/, are shorter than those from /a/, and differ less from the transitions to /t/.

The found differences between the three vowels contradict the expectations set up by our hypothesis. It may still be possible, however, that the differences are irrelevant for a listener. This would save the hypothesis and account for the lack of neutralization after vowels (Table 18). It is more likely, however, that these robust acoustic differences would result in different perception of the contrast after these vowels. /a/ would be a better context for correct identification than /i/. The results in the context of /u/ could be in between.

Environment	*Information*	*Identification*	*Contrast*
a__	**more**	**high?**	yes
u__	**less**	**low?/high?**	yes
i__	**less**	**low?/high?**	yes

Table 18. Acoustic information, identification, and contrast
in three vocalic environments

4.2 /t^j/ vs. /t/ after /a/, /u/, and /i/: Perception

Experiment 4 compares the perception of /t/ and /t^j/ after the vowels /a/, /u/ and /i/ in order to determine whether the found acoustic differences between the environments affect the perception of the contrast. This will be tested under two conditions, normal and with a removed palatalized burst.

4.2.1 Materials, procedure, and analysis

The minimal pairs used in the experiment are the same as in the previous experiment (Table 14). The procedure was identical to Experiment 2. There were three levels of the Burst factor: plain /t/, and two variants of words with palatalized /t^j/: one with a complete burst, and the other with the burst removed. This yielded a total of 864 tokens (6 stimuli × 6 Speakers × 2 repetitions × 12 listeners). In the analysis of response time (RT) only positive responses (i.e., all but errors in identification) were considered. RT of less than 50 ms and more than 2000 ms were excluded.[8]

The results, averaged across subjects and words, were evaluated by repeated-measures ANOVA with two within-subject factors: Burst (3 levels: plain, palatalized, and palatalized removed) and Vowel (3 levels: /a/, /u/, and /i/). The dependent variable corresponded to repeated measurements of identification with various combinations of factors. The same design was used to evaluate response time.

4.2.2 Results and discussion

Mean identification scores and response time results are presented in Table 19. Standard deviations are given in brackets.

Identification	*/t/*	*/t^j/*	*/t^j|/*
i__	1.000 (0.000)	0.993 (0.023)	**0.618 (0.211)**
u__	0.993 (0.023)	1.000 (0.000)	**0.750 (0.217)**
a__	0.970 (0.042)	1.000 (0.000)	0.937 (0.052)
Response Time			
a__	469 (131)	401 (137)	866 (260)
u__	451 (159)	387 (102)	868 (187)
i__	466 (149)	423 (127)	687 (169)

Table 19. Identification (out of 1) and response time (ms), final /t/, /t^j/, and [t^j|] after three vowels: Mean and standard deviation values, averaged across subjects

Both factors, Burst and Vowel were significant in terms of identification: [$F(2, 22) = 26.10$; $p < 0.001$] and [$F(2, 22) = 14.52$; $p < 0.001$] (Table 20). The interaction of Burst and Vowel was highly significant [$F(2, 22) = 23.18$; $p < 0.001$]. The Newman-Keuls test revealed the following significant differences: between /t^j/ and [t^j|] after /i/ ($p < 0.001$) and after /u/ ($p < 0.001$); between /t/ and [t^j|] after /i/ ($p < 0.001$) and after /u/ ($p < 0.001$); between all three vowels, /a/, /u/ and /i/ before [t^j|] ($p < 0.001$). There was no significant difference between /t^j/ and [t^j|] after /a/.

[8] The overall number of excluded tokens was 174 (30 with /t/, 9 with /t^j/, and 135 with /t^j/ with removed burst).

Identification	*DF*	*F*	*p*
Burst (plain-palatalized-palatalized removed)	2, 22	**26.104**	**0.000**
Vowel (a, u, i)	2, 22	**14.519**	**0.000**
Burst * Vowel	4, 44	**23.184**	**0.000**
Response Time			
Burst (plain-palatalized-palatalized removed)	2, 22	**158.768**	**0.000**
Vowel (a, u, i)	2, 22	2.837	0.080
Burst * Vowel	4, 44	**7.349**	**0.000**

Table 20. Perception and response time, final /t/, /t^j/, and [t^j|] after three vowels

The results for RT showed that the processing time of unreleased /t^j/ was significantly longer [F(2, 22) = 158.77; p < 0.001]. The increase in time in processing /t^j/ without burst, however, may be due to the editing of the signal. The effect of Vowel was not significant. There was an interaction between Burst and Vowel [F(4, 44) = 7.35; p < 0.001]. The results of the Scheffé test showed that the Burst difference was limited to /t^j/ vs. [t^j|] and /t/ vs. [t^j|]. The difference in processing of /t/ vs. /t^j/ was not significant.

The identification results are illustrated in Figure 6. While perception of the stops with full burst does not seem to be significantly affected by a vowel, the lack of palatalized burst is detrimental to the unreleased palatalized /t^j/ after high vowels, more in the case of /i/ than of /u/. In the context of /a/ the drop in identification is small.

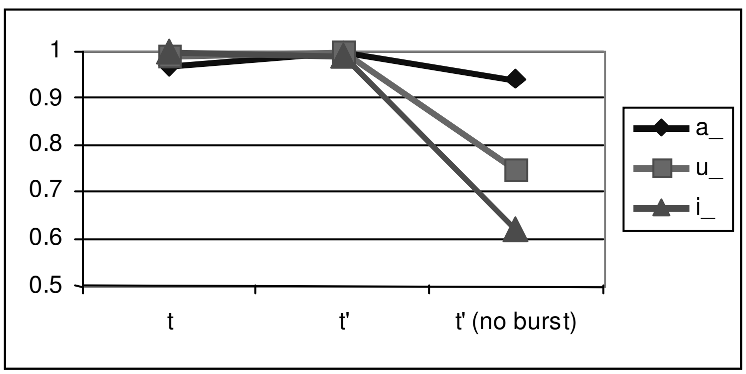

Figure 6
Perception of /t/ and /t^j/: post-vocalic environments

These results show that the quality of the preceding segment is very important for the identification of the plain-palatalized contrast. They confirm the acoustic findings that the three vowel contexts are different in terms of acoustic information. The results also run against the prediction by Licensing by Cue that no neutralization in these contexts would coincide with no difference in recognition rate (Table 21). As we know, there is neither categorical neutralization nor frequency effects after /u/ and /i/ in Russian.

Environment	*Information*	*Identification*	*Contrast*
a__	more	**high**	**yes**
u__	less	**lower**	**yes**
i__	less	**lower**	**yes**

Table 21. Acoustic information, identification, and contrast
in three vocalic environments

5. General discussion

We have seen that the hypothesis of Licensing by Cue makes correct predictions in some cases and sets up wrong expectations in others. It accounts for the neutralization of the Russian plain-palatalized contrast in coronals before consonants and fails to provide an explanation for the lack of neutralization after vowels.

A revised approach, outlined below, maintains the key assumption of Licensing by Cue that phonetic, primarily perceptual, factors are the main motivation for neutralization, and phonotactic patterns in general. However, it admits that mapping acoustic input to a phonological contrast is by no means direct and synchronic. This mapping is affected by a number of grammar-internal (Hale & Reiss 1999, Howe & Pulleyblank 2001) and external factors (see also Ohala (1981), (1983), Kawasaki (1982), Lindblom, MacNeilage, & Studdert-Kennedy (1983), Maddieson (1997), Silverman (1997), Browman & Goldstein (2001), Hume & Johnson (2001) for similar views).

Given inherent auditory limitations of a learner acquiring a language, not every sound in every context can be recovered equally well (Figure 7). The learner recovers a segment (or a gesture), if there is adequate acoustic information about it, and misses it or substitutes with another segment (or gesture), if the evidence for its presence is absent or inconclusive. The more informative the context, the higher the probability that the segment is recovered. Other phonetic, articulatory and aerodynamic factors contribute to the selection of the most stable phonetic patterns (See works cited above).

Listener-Speaker

Acoustic Signal		*Perception*		*Phonological Grammar*		
Information	⇒	Recovera-bility	⇒	Categoriza-tion	⇒	Contrast
more less	⇒	recovered missed	⇒	categorized	⇒	licensed neutralized

Figure 7
Schematic relations between acoustics, perception
and grammar in neutralization of a contrast

Phonetic and phonological universals and the implicational hierarchies can be largely explained by reference to these physical factors. But this is only a raw input to the grammar. The information about the contrast, recovered by the learner, is processed in a cognitive mode with reference to the phonological form, not to phonetic substance.[9] The grammar induces certain arbitrariness between the signal and its mental representation. As a result, ranking of phonotactic constraints in the grammar will follow the general pattern of the perceptual hierarchies, but will inevitably deviate from them in some arbitrary ways, generalizing across some phonological (e.g., environments and features), morphological (e.g., declension) and semantic (e.g., personal names, loans) domains.

Thus, failure of our listeners to perceive the phoneme /t^j/ under certain conditions before /n/ and /s/ indicates that these environments are less perceptually salient than the contexts before /k/. The reason is purely phonetic: the absence of a perceptible burst in the former contexts leads to a poorer recoverability of the palatal gesture by a listener. A learner is more likely to miss the underlying palatal gesture in words before /n/ and /s/ rather than before /k/. Based on this, s/he would construct a grammar that disallows palatalized segments before homorganic consonants (as in Russian). At the same time, the learner may over-generalize the neutralization context to all preconsonantal or all postvocalic (coda) positions constructing more restrictive grammars (as in, e.g., Irish, Lithuanian, Standard Bulgarian, or Nenets: see Kochetov 2001). One can expect the reverse development. A learner may extend the plain-palatalized contrast to all preconsonantal contexts, even in the lack of sufficient phonetic evidence for it. This pattern, while less common than the ones described above, is possible. Apparently, a dialect of Bulgarian (Khristov 1956, Chekman 1970, Schallert, p.c.) allows palatalized segments before consonants of all places of articulation.[10] The lack of neutralization after vowels /i/ and /u/ in Russian and other languages can be seen as another example of a phonological generalization that ignores the acoustic and perceptual details of different vowel contexts.

Some morphological and semantic peculiarities of the distribution of palatalized /t^j/ in Russian can be also accounted for by reference to generalization across morphological and semantic domains. Nouns of the third declension exhibit the neutralization of the /t^j/ to /t/ before /k/, while nouns of the first declension don't. This fact can hardly be explained by the direct influence of acoustic cues, but it is consistent with the diachronic view of neutralization, as a process gradually spreading through the lexicon. Recall also the semantic differences between the two groups of words. Many of the nouns that maintain the contrast are personal names or words denoting relatives, the items that have a rather transparent derivation.

In sum, the alternative approach presented here accounts for the facts of Russian and other languages, showing that neutralization of the plain-palatalized contrast, while induced by external phonetic factors, is regularized by the phonological structure.

[9] It is unlikely that a listener-speaker has to have a knowledge of relative salience of cues and perceptual hierarchies (*contra* Steriade 1997: 3-4), since perception does the job of filtering out less salient acoustic input (cf. Hale & Reiss 1999).

[10] The occurrence of /t^j/ before homorganic consonants in the dialect is limited mostly to inflectional morpheme boundaries. Transparent boundaries seem to be an additional condition for maintaining the contrast in a less cued environment (based on Khristov 1956).

6. Conclusion

This paper tested the hypothesis of Licensing by Cue by applying it to the distribution of the Russian plain-palatalized contrast in coronal stops in two environments. The hypothesis held that the maintenance of the contrast /t/ vs. /t^j/ should correspond to more acoustic information in the signal and higher identification rate and that its neutralization should be accompanied by fewer cues and lower recognition of the segments. The results support the hypothesis explaining the neutralization pattern before consonants: the plain-palatalized contrast before /k/ is more acoustically and perceptually salient than in the environments before /n/ or /s/. At the same time, the lack of neutralization does not follow from the experiments that showed the effect of vowel in terms of acoustics and perception. A revised approach was proposed to account for the results, treating neutralization as a product of acoustic and perceptual factors modified by phonological structural constraints. Further work is needed to determine details and possible patterns of this interaction.

To conclude, an explanation for neutralization, and phonotactic patterns in general, should not be sought only in phonology or only in phonetics, but in the interaction of *phonetic* factors with the *phonological* grammar.

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