A Cross-Language Study of the Production and Perception of Palatalized Consonants

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Abstract

The goal of this dissertation was to investigate experimentally the phonetic qualities of the palatalized consonants of Standard Bulgarian. The term 'palatalized' refers to consonants (e.g., [tʲ, dʲ]) which are articulated with a secondary palatal gesture superimposed on the primary gesture associated with their plain counterparts (e.g., [t, d]). An acoustic study investigated the claim (Horálek, 1950; Choi, 1998; Ignateva-Tsoneva, 2008) that the palatalized consonants of Standard Bulgarian have undergone depalatalization, which was defined as the decomposition of a secondary palatal [ʲ] gesture into a palatal glide [j]. A cross-language comparison was performed. Russian (e.g., [tʲulʲ], 'silk net') and British English (e.g., [tju:lip], 'tulip') data served as a baseline against which the Bulgarian data (e.g., [tʲul], 'silk net') was evaluated. Subjects' productions of words were recorded for acoustic analyses. The F1, F2 and F3 frequencies of the critical segments were analyzed with a Smoothing Spline ANOVA (Gu, 2002). The analyses indicated that Bulgarian palatalized consonants were identical to those of the Russian palatalized consonants, but different from the consonant-palatal glide sequences of British English. It was concluded that Bulgarian palatalized consonants have not undergone depalatalization.

A perception study employed two variations of the gating task (Grosjean, 1980): audio-only and audio-visual. The results of the audio-only experiment indicated that Bulgarian and Russian listeners needed only the information associated with the palatalization portion of the consonant to identify it as palatalized. Bulgarian subjects did not need the transitions with the following vowel (Tilkov, 1983) to identify a consonant as palatalized. The Russian subjects of Richey's (2000) experiment did not need the formant transitions either to identify the secondary palatal gesture. These findings provide further evidence that the palatalized consonants of the Standard Bulgarian have not undergone depalatalization. The purpose of the audio-visual experiment was to investigate if Bulgarian and Russian listeners use visual information to identify palatalized consonants. The results from this experiment were not as clear cut as those from the audio-only experiment. Factors such as insufficient visual information at earlier gates, as well as attentional load are being considered as possible confounds. In addition, an improved methodology for an audio-visual perception study is outlined.

Experimental evidence from the acoustic and perception studies points to similarities in the phonetic shape of the palatalized consonants of Bulgarian and Russian. However, the phonological distribution of these segments is very different in the respective languages. I argue against a one-to-one mapping between the phonetic and phonological representations of the Bulgarian palatalized consonants. Based on distributional evidence, I propose that at the level of phonology they consist of a sequence of /CjV/.

This dissertation is dedicated to my mother and the Bulgarian language.

Посещавам тази дисертациа на майка ми и на българския език.

“Аз съм българче и силна
майка мене е родила;
с хубости, блага обилна
мойта родина е мила.

Аз съм българче. Обичам
наште планини зелени,
българин да се наричам -
първа радост е за мене. . .”

Из “Аз съм българче”, Иван Вазов (1850 – 1921)
From “I am Bulgarian”, by Ivan Vazov (1850 – 1921)

Acknowledgements

One often hears in life that it is important to be “in the right place, at the right time”. In my early years as a graduate student, I was fascinated with the work of Jeff Mielke and wished I could work with him. It never occurred to me that it could actually happen, but it did. In 2006 he was appointed a professor in the Department of Linguistics and, soon after, I started working with him. The topic of this dissertation emerged as a result of Jeff encouraging me to do a cross-language research and my discovery that the phonetic qualities of palatalized consonants of Standard Bulgarian had not been researched experimentally for a very long time, and that their existence had been questioned. I am most grateful to Jeff for becoming my thesis advisor and for allowing me to pursue my interests in phonetics, speech perception and phonology through this topic. Thank you, Jeff, for generously sharing your knowledge with me, and for all your support and encouragement!

This dissertation has benefited from the comments of my committee members: Ian MacKay, Marc Brunelle, Lev Blumenfeld and Molly Babel. I am particularly grateful for the encouragement I received to consider the implications of the experimental findings for phonological theory. The comments of my external examiner, Molly Babel, have given me a lot of ideas for a cross-dialectal socio-phonetic research in Bulgarian. I would also like to express my gratitude to my internal committee members for being my teachers and mentors during my studies. Ian introduced me to acoustic phonetics as an undergraduate. I was somewhat anxious taking his acoustic phonetics class. However, driven by curiosity in the subject, I enrolled in it. Being a wonderful teacher, Ian eased my anxiety and sharpened my interest in acoustic phonetics. It is fair to say that he planted some of the seeds for the acoustics study a long time ago. Marc’s seminar on the phonetic-phonology interface was the first of its kind in the department and it helped me a lot to understand certain issues in laboratory phonology. Lev's work in Russian phonology deepened my interests in another Slavic language. No wonder Russian became part of my cross-linguistic research.

The studies in my dissertation have been influenced by my training in psychology. I could not imagine doing experiments without any courses in research methods and statistics. Special thanks are due to two of my teachers from the School of Psychology: Catherine Plowright and Alain Desroshers. Catherine first introduced me to cognitive psychology as an undergraduate and, then, invited me to take her graduate seminar in Cognition, allowing me to focus on language. Alain also invited me to take his graduate seminar in Cognitive Psychology of Language, which concentrated on the phonology of reading, as well as models of the phonological lexicon. Importantly, both Catherine and Alain have supported and encouraged me during my graduate studies.

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I am most indebted to my family for their love, understanding and patience during my graduate studies. I would not have been able to pursue degrees in Linguistics and Psychology without the moral and financial support of my husband Kevin. My parents have supported my academic endeavours throughout my life. My dad Georgi is not with us any longer but I know he would have been extremely proud of my Doctorate in

Linguistics. My mother Gina has been a constant source of strength in my life and has supported me unconditionally in every aspect of it. This dissertation is devoted to her and the Bulgarian language.

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Chapter 1

Introduction

The goal of this dissertation is to experimentally investigate the acoustic and perceptual attributes of palatalized consonants of Standard Bulgarian and to compare them to those of Standard Russian[1]. In this work, the term 'palatalized' refers to consonants (e.g., [tʲ dʲ]) which are articulated with a secondary palatal gesture superimposed on the primary gesture associated with their plain counterparts (e.g., [t d]). Following Ladefoged and Maddieson (1996), I define a secondary palatal gesture as a gesture where the tongue-body position assumes a high, front tongue body position like that of the vowel [i].

The choice of Russian for a cross-language comparison is important. The presence of palatalized consonants in Russian is undisputed. In Bulgarian, however, the presence of palatalized consonants in the phonetic and phonemic inventory of the language is disputed. A direct comparison between the two languages should help to establish the existence, or lack of, these consonants in Bulgarian. Both languages have been described as having pairs of plain and palatalized consonants which can be used contrastively to denote a change in word meaning (for example, [tʲul], 'silk net; Bulgarian' and [tul], 'sheepskin; Bulgarian'). Unlike Russian, the Bulgarian palatalized counterparts appear in very restricted environments: only in syllable onsets and before the back vowels [u a ɔ].

The limited distribution of Bulgarian soft consonants has prompted some scholars to question their existence in Bulgarian. Horálek (1950) went as far as to suggest the complete lack of soft consonants in Bulgarian. He hypothesized that the secondary

[1] From now on, any mention of the Bulgarian and Russian languages should be assumed to refer to the standard varieties.

palatal gesture [^{j}] had decomposed into the palatal glide [j]. Thus, [t^jul] (silk net) would be articulated as [tjul]. In the latter word, the palatal glide has the phonetic status of a primary gesture. More recently, Choi (1998) has argued that Bulgarian lacks the soft/hard phonemic opposition. In other words, there are no soft consonants in the phonemic inventory of the language. His claim is based on circumstantial evidence. He observes that an L2 Korean learner of Russian has difficulty mastering the soft consonants of the language. However, if a Korean learns Bulgarian as a second language, no such problems are encountered. Moreover, according to Choi, the Korean learner of Bulgarian is unaware of the existence of such consonants. In the spirit of Horálek (1950), the Choi claims that the secondary gesture of palatalized consonants has become 'detached' and evolved into a primary palatal articulation. Thus, the Bulgarian word [l^jato] ('summer') has the surface phonetic shape [l^jjato]; the phoneme /l/ has two allophones, [l] and [l^j]. Furthermore, the palatalized allophone is the result of coarticulation with the following palatal glide [j].

The status of palatalized consonants in Standard Bulgarian was recently revisited by Ignateva-Tsoneva (2008). She rejects their existence basing her claim on the limited distribution of these consonants and the arguably speculative views of scholars like Horálek (1950) and Choi (1998). Ignateva-Tsoneva (2008) asserts that the glide [j] is the only Bulgarian consonant with a palatal place of articulation. She does not refer to any experimental evidence to back up her claims.

There are only a handful of studies that investigate the phonetic and phonemic qualities of Bulgarian palatalized consonants. The most recent one is that of Barnes (2002), who conducted an experiment to test the phonemic status of soft consonants. He employed a word-blending experiment which consisted of reversing the syllable-initial consonants of 'two-word expressions'. For example, on hearing a phrase, such as [b^jala kɔfa], ("white bucket"), subjects were expected to form two novel words by switching the syllable-initial segments. It was hypothesized that if subjects transposed [b^j] ([b^jɔfa]), this would count as evidence for the existence of soft consonants. If they said [bɔfa], instead, the inference would be that the original word consisted of a consonant-glide sequence. The results of the experiment could not be unambiguously interpreted as providing support for one hypothesis over another because they were confounded by the orthography of palatalized consonants (Barnes, 2002). The presence of palatalized consonants is signaled by the grapheme /ь/, which is separate or, most frequently, part of the following vowel. As mentioned earlier, palatalized consonants are found only before the vowels [ɔ], [a] and [u], which correspond to the Bulgarian vowel graphemes 'o', 'a' and 'y', respectively. The following combinations are possible: 'ю' = /ь + y /, [^{j}u]; 'я' = /ь + a/, [^{j}a]; 'ьo' = /ь + o/, [^{j}o]. Thus, it is possible that subjects simply manipulated orthographic symbols (which represents consonants and palatalization separately), and their willingness to treat consonants and palatalization independently in the experiment may reflect this orthographic knowledge, rather than linguistic knowledge.

The only articulatory study of Bulgarian palatalized consonants was conducted by Stojkov (1942, 1961). He took x-ray tracings of vocal tract configurations of Bulgarian plain-palatalized consonantal pairs. Based on the inspection of those, Ladefoged and Maddieson (1996) note that the major difference between [t^j d^j n^j] and [t d n] consists in the apical dento-alveolar gesture and the laminal dento-alveolar gesture, respectively (Figure 1.1).

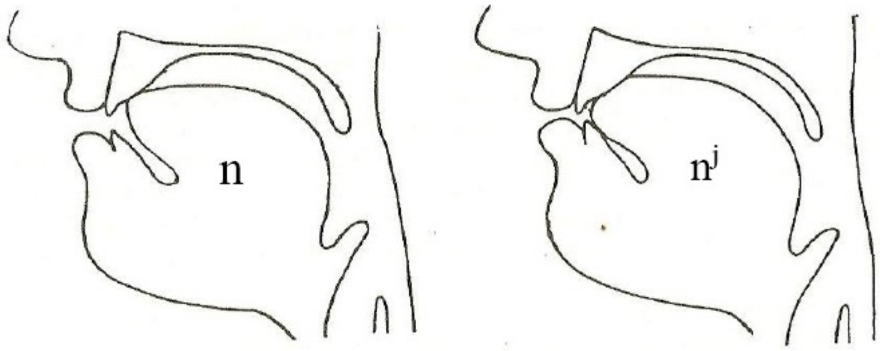

Figure 1.1 Tracings from x-ray photographs of Bulgarian [n] and [nʲ].
(After Stojkov, 1961).

It is interesting that, during the articulation of [nʲ], the tongue body is not displaced towards the hard palate, which is typical of palatalized consonants. There is an increased surface contact of the tongue front, which results in the modification of the primary articulatory gesture. Scatton (1984) also observes that the position of the mid-tongue-body of the palatalized stops is not much higher than that of their plain counterparts (Figure 1.2).

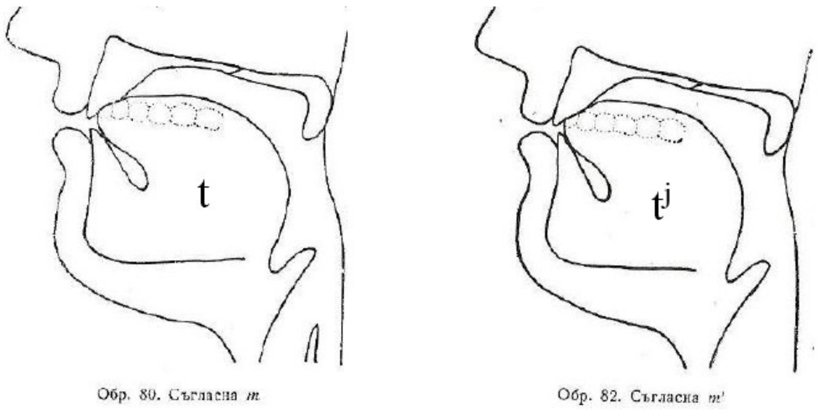

Figure 1.2 Tracings from x-ray photographs of Bulgarian [t] and [tʲ].
(After Stojkov, 1961).

This is in sharp contrast with the Russian x-ray contours (Daniel & Ward, 1969) where the major difference consists of the high tongue body 'i-like' position of the palatalized consonants (Figure 1.3). Ladefoged and Maddieson (1996) define 'palatalization' as the "superimposition of a raising of the front of the tongue toward a position similar to that for [i] on a primary gesture" (p. 363).

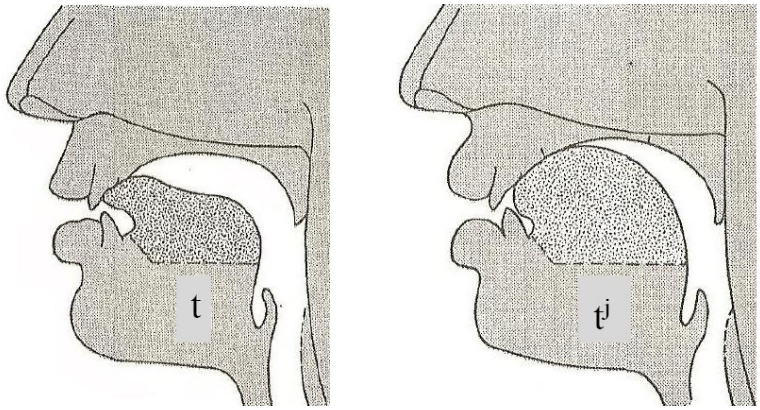

Figure 1.3 Tracings from x-ray photographs of Russian [t] and [tʲ] . (After Daniel & Ward, 1969).

Let us compare the tongue fronts of the Bulgarian and Russian [tʲ], based on Figures 1.2 and 1.3, respectively. To begin with, in both languages, [t] is a dento-alveolar articulation. The tip of the tongue touches the back of the front incisors and the blade of the tongue touches the alveolar ridge. With regards to [tʲ], in Russian, both the tongue blade and tip are raised towards the hard palate (the secondary /i/-like gesture is causing a movement away from the back of the incisors); in Bulgarian, the tongue tip remains behind the incisors and the tongue blade is only slightly raised toward the hard palate. It is immediately obvious that only the Russian [tʲ] complies with the above definition of palatalized consonants. In case of the Bulgarian [tʲ], the tongue front does not assume the height of an /i/-gesture. There are two implications from these observations: (1) we may need to modify the definition of palatalization as stated by Ladefoged and Maddieson (1996); or (2) the Bulgarian soft consonants have lost their 'palatalized' status. The statement in (2) means that the soft consonants have lost their secondary palatal gesture.

Thus, instead of the sequences [C^ja, C^jo, C^ju], we now have [Cja, Cjo, Cju], respectively. The reader is directed to Appendix 1, page , for more comparisons between Bulgarian and Russian palatalized consonants.

In addition to the articulatory data, there is evidence from perceptual experiments which points to possible differences between Bulgarian and Russian palatalized consonants. Tilkov (1983) conducted an experiment which tested the perception of plain and palatalized consonants in Bulgarian. Minimal pairs with the plain and palatalized consonant word-initially (e.g., [marka-m^jarka], 'stamp-measure'), with the primary stress on the first syllable, were spliced together, combining palatalized consonants with the formant transitions of plain consonants, and vice versa. His results indicated that plain consonants could be identified from the duration and spectral shape of the burst alone. With the exception of the palatalized velars [k^j g^j x^j], the Bulgarian listeners needed the formant transitions to identify the remainder of the consonants as soft.

The Russian participants in Richey's (2000) study did not need formant transitions to identify palatalized consonants. The information contained in the duration and frequencies of the spectral burst of plosive consonants was sufficient for them to perceive them as palatalized. Richey manipulated spectral burst shapes, burst durations, and formant transitions of plain and palatalized consonants. In a perception experiment, native Russian speakers listened to various consonant-vowel stimuli. When they heard only the formant transitions, they were able to identify place of articulation of plain stops, but not palatalized stops. When they were presented with stimuli with conflicting cues for place in the burst and formant transitions, plain consonants were identified on the basis of formant transitions but palatalized consonants on the basis of the burst. Richey concluded that the cues for place of articulation of palatalized consonants were identified on the basis of the burst.

In summary, based on the experiments of Tilkov (1983) and Richey (2000), perceptual cues contained in the spectral burst shape and spectral duration are sufficient for the identification of the place of articulation of palatalized consonants in Russian but not in Bulgarian. Bulgarian palatalized consonants rely on perceptual cues in the formant transitions for their correct identification.

We have now seen that independent pieces of articulatory and perceptual data point to the possibility that at least some of the Bulgarian palatalized consonants have different phonetic qualities from the Russian palatalized consonants. While the results of these studies are not disputed, they are not directly comparable. To begin with, we do not know what type of stimuli (e.g., one- or two-syllable words) were used in the articulation and perception studies. It appears that the critical segments occurred word-initially, but we cannot be certain of it. Unless the environment (e.g., 1^{st} or 2^{nd} syllable position) is controlled, articulatory dynamics would vary even for the same consonant (Fougeron & Keating, 1997). Different stress placement (e.g., 1^{st} or 2^{nd} syllable) will also cause variability in articulation and perception of segments. With regards to the perception experiments, we do not have the technical details of where the splicing of the different type of segments occurred. Thus, differences in the perception of palatalized consonants could be the result of the different stimuli, or the different procedures used in the preparation of stimuli. The goal of the current research is to directly compare the phonetic qualities of palatalized consonants in Bulgarian and Russian. To investigate these qualities, I employ an acoustic study and an audio-visual perception study. Each study uses the same experimental paradigm and identical stimuli for both languages.

1.1 Overview of the Chapters

Two major studies were undertaken to investigate the phonetic qualities of the palatalized consonants of Standard Bulgarian, an acoustic study and an audio-visual perception study. The acoustic study is described in Chapter 2. Audio-only and audio-visual studies are described in Chapter 3 and 4, respectively. These chapters detail the hypotheses, methodologies, statistical analyses and results of the experiments. In the acoustic (Chapter 2) and audio-only perception (Chapter 3) studies, the results are compared across languages. The results from the audio-visual perception study (Chapter 4) are presented individually for each language as research has indicated that there are differences in the interpretability of the visual articulatory gestures across speakers (Kridos & Lesner, 1982). Chapter 5 considers the implications of the experimental findings for phonological theory with a reference to the phonological representations of Bulgarian palatalized consonants. Chapter 6 generalizes the results across studies and concludes that, on the basis of these data, Bulgarian palatalized consonants have not undergone depalatalization.

Chapter 2

Cross-Language Comparison of C^jV/ CjV Sequences – An Acoustic-Phonetic Study

2.1 Experimental Hypotheses

We have now seen that independent pieces of articulatory and perceptual data point to the possibility that at least some of the Bulgarian palatalized consonants have different phonetic qualities from the Russian palatalized consonants. The goal of this study was to investigate whether the palatalized consonants of Standard Bulgarian have undergone depalatalization, which is defined as the decomposition of a secondary palatal $[^j]$ gesture into a palatal glide [j]. To this end, a cross-language comparison was performed. Russian (e.g., $[t^jul^j]$, 'silk net') and British English (e.g., [tju:lip], 'tulip') data served as a baseline against which the Bulgarian data (e.g., $[t^jul]$, 'silk net') was evaluated. For the null hypothesis to be rejected there must be evidence that Bulgarian has a sequence of a plain consonant, a palatal glide, and a back vowel (e.g., [tju]).

Southern British English has a falling diphthong (MacKay, 1987) made up of a sequence of the palatal glide [j] and the back vowel [u]. There are minimal, or near-minimal, pairs in which the glide contributes to the contrast, for example, 'few' [fju:] vs. 'fool' [fu:l]. Acoustically, the main difference between a consonant-palatal glide sequence and a palatalized consonant is that the former includes a steady state interval associated with the palatal glide, before the transitions with the following vowel begin (Ladefoged & Maddieson, 1996). The duration of the steady state interval of a palatal glide in Bulgarian may not be the same as in Southern British English. It may be closer in duration to that of Russian consonant-palatal glide sequences. It was not possible to use Russian stimuli for the depalatalization comparison. Although Russian has [Cj] sequences which contrast with $[C^j]$ (e.g., [pjot], "drink" vs. $[p^jotr]$, "Peter"), there are very few that occur in syllable-initial position only, and thus match the restricted distribution of Bulgarian soft consonants.

2.2 Method

2.2.1 Design and apparatus

The study employed a within-subject, 2 x 2 (Bulgarian and Russian) and 2 x 1 (British English) factorial designs. The independent variables were the type of consonants (plain vs. palatalized) and vowels ([a] and [u]) found word-initially. Only the vowel /u/ applied to the British data. The consonant [r] was excluded from the British stimuli as it is phonotactically illegal word-initially, before the palatal glide. Furthermore, the back vowel [ɔ] was excluded from the Bulgarian and Russian stimuli as there are very few Bulgarian palatalized consonants in this environment. Therefore, no consistent comparison between the two languages in the context of [ɔ] could be made. The dependent variables were the acoustic measures associated with the secondary palatal gesture and the palatal glide, which represented all possible segmental environments compared across languages. The latter are presented in Table 2.1.

Table 2.1 Segmental Environments across Languages

	Bulgarian	Russian	British English
Vowel [u]	p-pʲ, b-bʲ, t-tʲ, d-dʲ, k-kʲ, g-gʲ, f-fʲ, v-vʲ, s-sʲ, z-zʲ, l-lʲ, r-rʲ, m-mʲ, n-nʲ	p-pʲ, b-bʲ, t-tʲ, d-dʲ, k-kʲ, g-gʲ, f-fʲ, v-vʲ, s-sʲ, z-zʲ, l-lʲ, r-rʲ, m-mʲ, n-nʲ	p-pj, b-bj, t-tj, d-dj, k-kj, g-gj, f-fj, v-vj, s-sj, z-zj, l-lj, m-mj, n-nj
Vowel [a]	p-pʲ, b-bʲ, t-tʲ, d-dʲ, k-kʲ, g-gʲ, f-fʲ, v-vʲ, s-sʲ, z-zʲ, l-lʲ, r-rʲ, m-mʲ, n-nʲ	p-pʲ, b-bʲ, t-tʲ, d-dʲ, k-kʲ, g-gʲ, f-fʲ, v-vʲ, s-sʲ, z-zʲ, l-lʲ, r-rʲ, m-mʲ, n-nʲ	N/A

The critical segments appear word-initially for all languages. The primary stress falls on the initial syllable. The ratio of experimental to distracter stimuli is as follows: 1:1 for Bulgarian and Russian, 1:2 for British English. The ratio is higher for English as there are fewer experimental stimuli and greater possibility for the subjects to guess the purpose of the study. There are 7 repetitions of each stimulus word. Great care was taken to select real stimuli in order to preserve the ecological validity of the study. It was necessary to construct a few nonsense words to be able to compare the effects on the dependent variables across all three languages. Furthermore, to compare the plain with the palatalized consonants, minimal, or near-minimal pairs for all consonants were selected, for all vowel environments (The stimuli are presented in Appendix 2, page). The stimuli were distributed across blocks with the aid of a partially balanced Latin square. This procedure yielded 28 blocks, each consisting of 21 trials for British English and 28 trials for Russian and Bulgarian. There is also a practice block with the abovementioned number of trials for each language.

The order of presentation of all blocks, and the stimuli within them, was randomized for each subject by the experimental software E-Prime (Schneider, Eschman, & Zuccolotto, 2001). Each participant experienced all levels of the independent variables. The speed of presentation was set through the software to control for hyper- and hypo-articulation effects. The duration of the sentence frame determined the speed of presentation for each language: 2.9s, 3.0s, and 3.4s for English, Bulgarian and Russian, respectively. These measures were made during some test recordings, which involved the reading of stimulus pairs within the sentence for each language. In the sentence frame, the sound preceding the stimulus was the same for each language, [ə]. The latter was selected such that it would not greatly influence the articulation of the critical segments through coarticulatory effects. The sentence frames are listed below.

- British English: [giv mi ə **du:m/dju:n** əˈgen] (Give me a …… again)
- Bulgarian: [tʲa ˈkazə ˈ**dunɤv**/ˈ**dʲunɤ** sɛˈga] (She said …… now)
- Russian: [əna skəˈzalə ˈ**dunut**/ˈ**dʲunə** seˈʧas] (She said …… now)

Data were recorded at 44.kHz, 24 bits per sample, on a Marantz PMD660 digital recorder using a Sure SM10A microphone through a Symetrix SX202 preamplifier. The digital recorder had the following settings: Input – XLR Mic; Output – USB to PC; Recording format – PCM 44.1k; Meter Mode – Normal; Microphone attenuation – 0; Level continuation – manual. Two Russian and one British subjects were recorded without the preamplifier. However, this did not seem to affect the analyses of their recorded data.

2.2.2 Participants

Native speakers (8 Bulgarian, ages 19 – 42, Mean = 30, SD = 8; 8 Russian; ages 18 – 47, Mean = 31, SD = 10; 8 British; ages 28-66, Mean = 50, SD = 12) of the languages of interest were recruited for the experiment. All of the participants had completed their primary and secondary schooling in their native countries. Most of the British English subjects were recruited through the British High Commission in Ottawa. None of them reported any speech or languages deficits. All subjects signed a consent form prior to the recording session. They were recruited on a volunteer basis and were not paid for their participation in the study.

2.2.3 Procedure

Participants were seated in front of a computer monitor in a sound-proof room. They wore a headset microphone, with the microphone placed 2 cm away from the corner of the mouth. Their task consisted of reading the stimuli within the same sentence frame over the microphone. All subjects started with a practice session to become familiar with the recording procedure. The experimenter was present during the practice session to set up the recording level. For each subject, the recording level was adjusted on the preamplifier. After that, subjects were left alone to begin the actual recording session. When they were ready to begin reading, they pressed the space bar, upon which a screen with the reading instructions appeared. They were instructed to read the sentences with their natural voices and at a regular speed. Their productions were recorded on the digital recorder. The participants had the option to press a key if they wished to pause the recordings in order to take a break, or to terminate the experiment. Three breaks were imposed in order to reduce tiredness effects.

2.3 Data Analyses

2.3.1 Acoustic Analyses

The recorded speech was transferred from the digital recorder to Praat (Boersma & Weenick, 2008), software for acoustic analyses. Each individual file was broken down into several smaller size files to reduce memory demands. At the initial stage, all words were segmented automatically with the aid of a Praat script[2]. The script referred to a text file, produced with E-Prime, to follow the order of the randomly presented stimuli. Thus, a Praat text-grid with two tiers, words and segments, was generated. At the next stage, a manual realigning between the corresponding sounds from the sound file and the segment tier was performed.

[2] Mielke, J. (2008). *Praat Script for Automatic Word Segmentation*.

Following the manual re-aligning of the segments, the F1, F2 and F3 frequencies of the crucial segments (word-initial plain and palatalized consonants) were recorded automatically with the aid of a Praat script[3]. Measurements were taken at every 0.10 seconds, during the interval from the release of each consonant until the end of the neighbouring vowel. For the plosive consonants, measurements stared at the burst. An extensive inspecting and re-measuring of the frequency values was performed manually to ensure that all figures were correct.

2.3.2 Statistical analyses

The formants data was subjected to statistical analyses with the statistical software R (Version 2.6.1., R Development Core Team, 2008). A Smoothing Spline ANOVA (henceforward, SSANOVA) (Gu, 2002) was performed on each subject's data for each formant contour for all critical pair of segments. The data was subjected to a Smoothing Spline ANOVA (SSANOVA), a statistical technique which determines if the shapes of multiple data curves (e.g., regression curves) are significantly different from one another. The technique was introduced to linguistic research by Davidson (2006), who applied it to the comparison of tongue curves acquired through ultrasound imaging. By examining tongue curves, she determined if given articulations were the same or different when some context was varied. For example, the articulation of a word final consonant in 'blac**k** top' was compared to the word medial consonant in 'blac**k**top'. Subsequently, Baker (2006) used SSANOVA to test the differences in the formant contours of vowels, e.g., the vowel [æ] in 'b**a**d' vs. 'b**a**n', or, 'b**a**n' vs. 'b**a**m'. This technique has an advantage over the traditional method of vowel formant analysis which

[3] Mielke, J. (2008). *Praat Script for Extracting Formant Frequencies*.

measures the formant value at the vowel midpoint, and is often criticized for providing static information only, excluding dynamic information found at the beginning and end of the vowel, which is related to formant transitions between the vowel and the neighboring segment.

As mentioned above, the collected data, which consisted of formant contour frequencies sampled at discrete time points, underwent a regression analysis in R, the statistical software, with the aid of a SSANOVA formant code (Baker, 2006). A Smoothing Spline ANOVA is performed as follows. A polynomial function connects discrete data points to construct a smoothing spline. Furthermore, the function consists of two terms, one that attempts to fit the data, and one that penalizes the fit (Davidson, 2006). The resulting spline is a regression line with suitable amounts of fines. In this study, the smoothing splines represent formant contours. Those are plotted on a graph, as illustrated in Figures 2.4 and 2.5.

The graphs consist of two axes: (1) the time in seconds is on the horizontal axis, and (2) the formant frequencies in Hz on the vertical axis. The F1, F2 and F3 formant contours are depicted in solid green and red colours for the palatalized and plain sequences, respectively. Confidence intervals (95%) (green and red dotted lines) are plotted on each side of the formant contour. If points of two curves along the time dimension do not overlap, we can be confident that they are distinct, and the difference is statistically significant.

In Figure 2.4, the F2 confidence intervals overlap at 0.06 seconds (along the time dimension). Prior to this point, the F2 formant contours, together with the confidence intervals, are separated for [zu] and [zʲu], indicating their F2's are distinct. In Figure 2.5, the F2 confidence intervals overlap at 0.11 seconds. Thus, there is a difference of 0.05

seconds between the two subjects, before the confidence intervals of the F2 contours overlap. In other words, the [zu – zju] contrast exists for both subjects, but for subject B2, this contrast is maintained for a further 0.05 seconds.

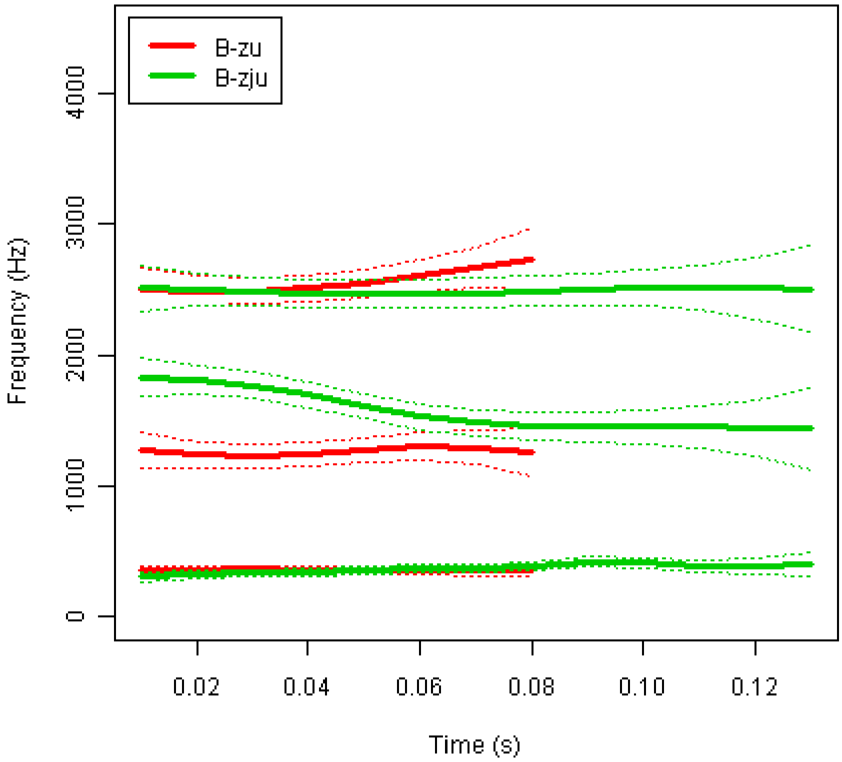

Figure 2.4 SSANOVA graph for [zu] & [zʲu][4], Bulgarian

Furthermore, in Figure 2.5, the confidence intervals surrounding the interaction effect are wider, compared to those in Figure 2.4. The inference is that there is a greater variability for F2 values for the subject in Figure 3.5 and lesser variability for the F2 values for the subject in Figure 2.4 (Davidson, 2006). In addition, looking at the slope of the formant contour of the sequence with the palatal segment, we can assume that it represents the

[4] Please note that the CʲV for Russian and Bulgarian are shown as CjV in the graphs due to inability of “R” to insert phonetic symbols.

transitions between the palatal glide, be it a primary or a secondary gesture, and the following vowel.

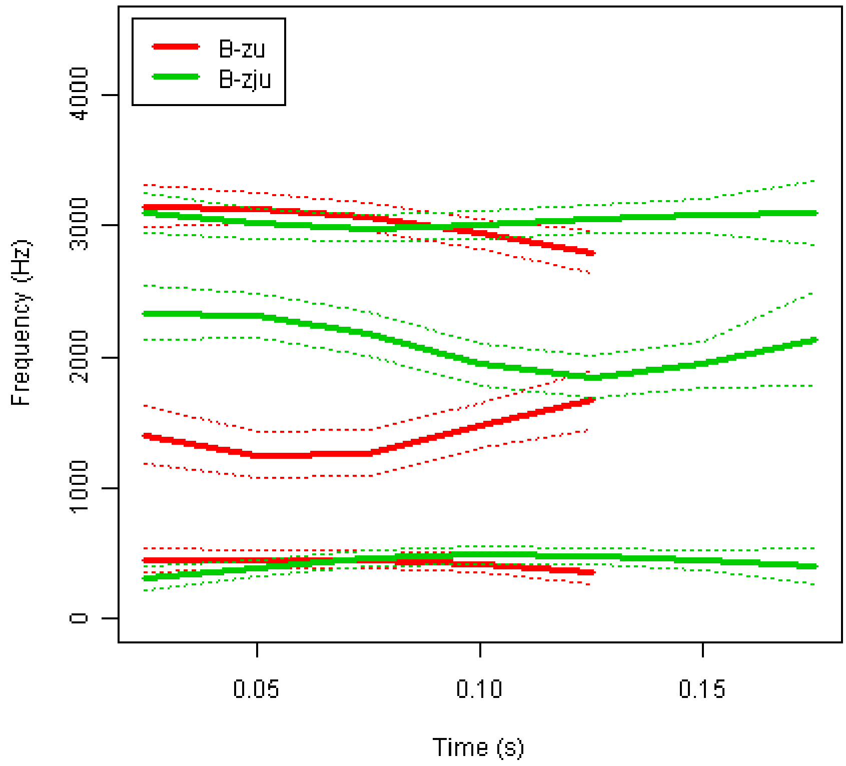

Figure 2.5 SSANOVA graph for [zu] & [zʲu], Bulgarian

2.4 Results

2.4.1 Plain and Palatalized Plosive Consonants Contrasts in the context of [u a]

Figures 2.6a and 2.6b are representative SSANOVA graphs of the [pu – pʲu] contrast for the Bulgarian subjects. As indicated by the F2 formant contours, the contrast is maintained in the language. For half of the subjects (as in Figure 2.6a), the F2 confidence intervals overlap, on average, at 0.10 seconds along the time axis. This overlap occurs at an interval when the contours of the two segmental sequences flatten, and the steady state of the vowel begins. During this period, the vowels should have identical F2 frequencies. For the remainder of the subjects, the F2 lines do not come together (as in Figure 2.6b), though they are not far apart. It is likely that the F2 of the vowel from the palatal sequence is higher than that of the vowel from the plain sequence due to coarticulatory effects caused by the palatal gesture.

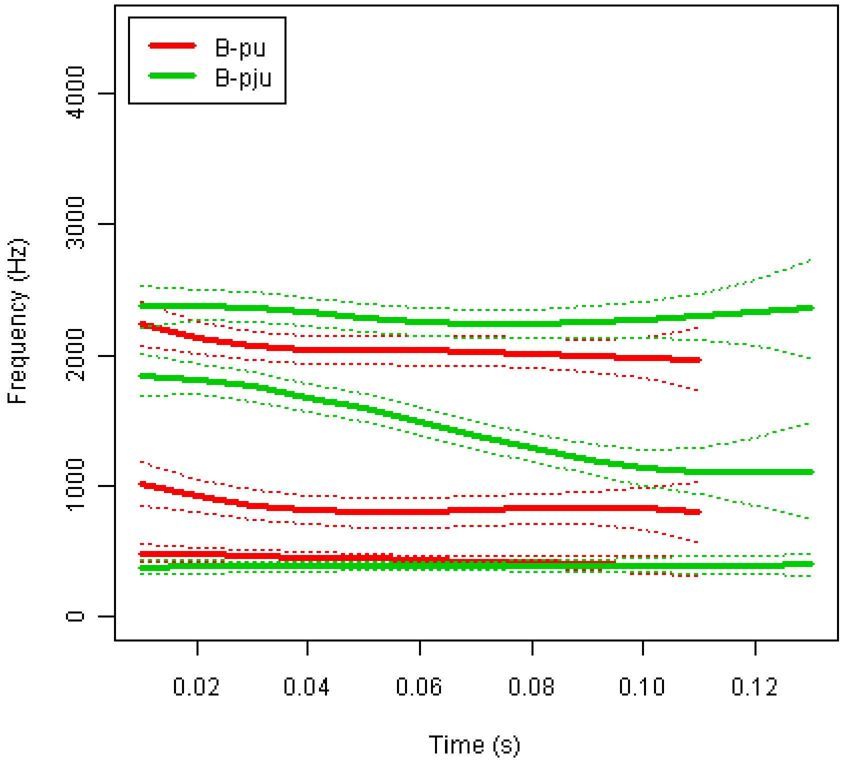

Figure 2.6a SSANOVA graph for [pu] & [pʲu], Bulgarian

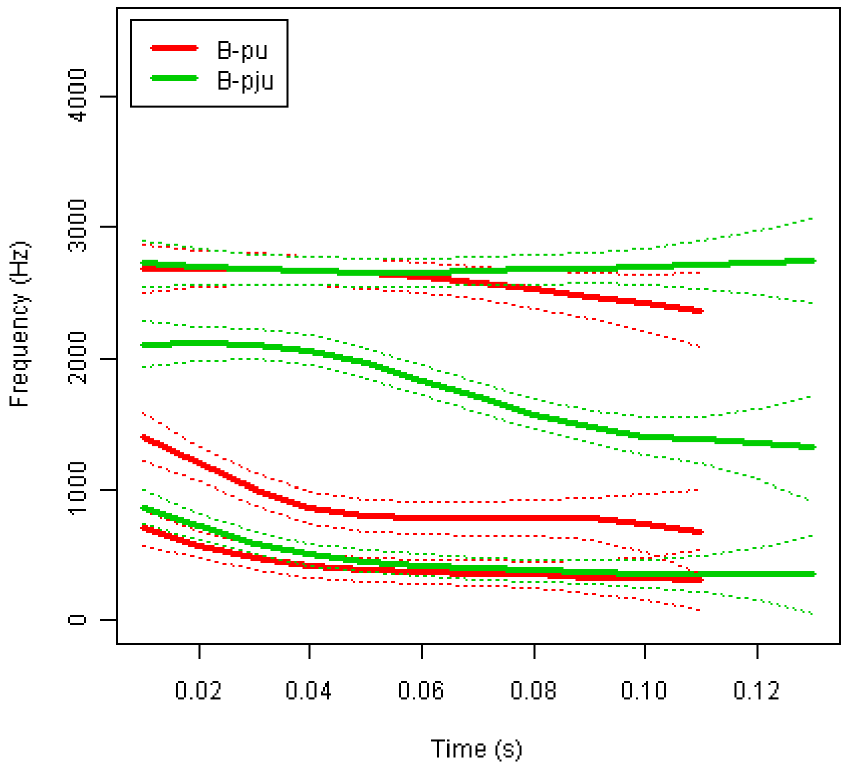

Figure 2.6b SSANOVA graph for [pu] & [pʲu], Bulgarian

The F1 and F3 contours largely overlap in the graphs of all subjects, which suggests that the palatalization process has changed/raised the second formant only. What is not clear from the graphs is whether or not the palatal gesture is a primary or a secondary articulation. We will come back to this question once we have compared these graphs to those of the Russian and British subjects.

With reference to the Russian SSANOVA graphs (Figure 2.7 below is representative of the data), the F2 confidence intervals overlap, on average, at around 0.10 seconds along the time axis. This is the same average figure as for the Bulgarian data. In other words, for both languages, the F2 lines for the [pu – pʲu] sequences remain different for a period of 0.10 seconds. Furthermore, we can be certain that this difference is statistically significant. Another similarity among the F2 contours of the [pʲu] sequence is that they begin with a flattish portion, which then slopes down before flattening again.

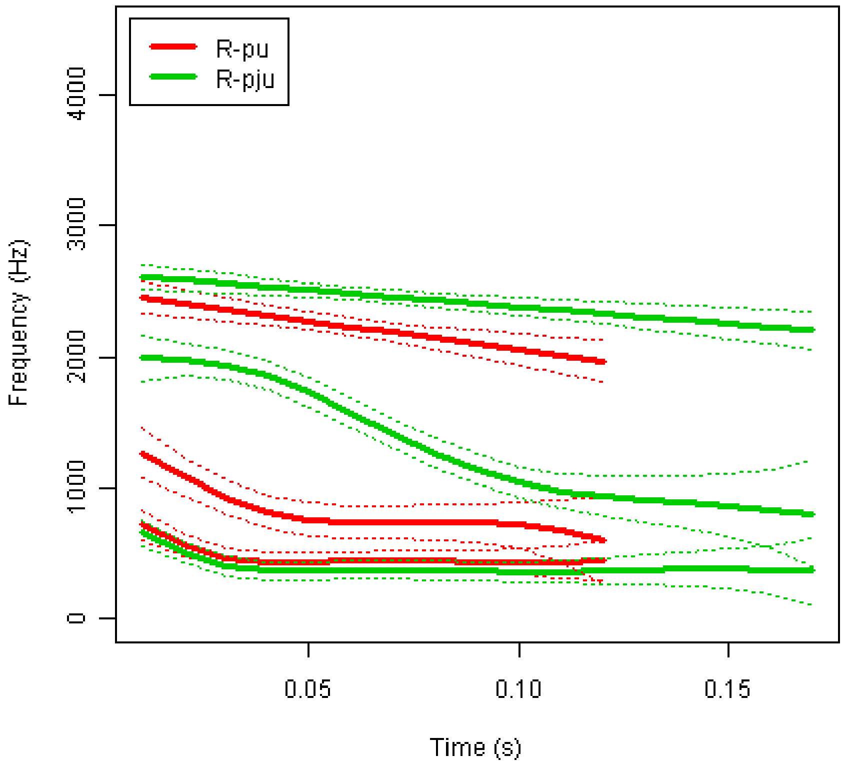

Figure 2.7 SSANOVA graph for [pu] & [pʲu], Russian

As it was the case with the Bulgarian data, there is no significant difference between the F1 contours of [pu] vs.[/pʲu]. For both languages, there is somewhat more variability with regards to the F3 contours. This is not surprising, as F3 has been associated with individual characteristics, such as voice quality (Ladefoged, 1993), among others. Overall, the F2 contours of [pu] vs. [pʲu] look very similar for both languages.

Next, we turn to the SSANOVA graph in Figure 2.8, which is representative of the British [pu – pju] data. The most remarkable difference between British English and the Slavic languages is that the F2 lines of the British [pu – pju] sequences do not overlap for 0.15 seconds, on average. It is possible that the longer duration prior to the F2 contour overlap is due to the longer VOT of the English voiceless plosives, as well as the longer palatal glide element associated with the falling diphthong.

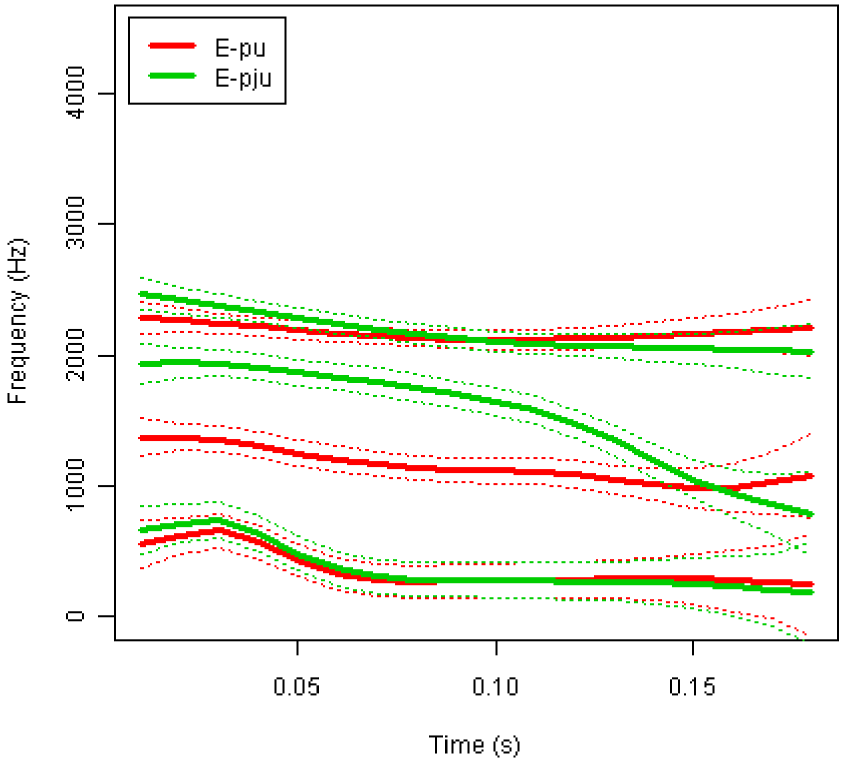

Figure 2.8 SSANOVA graph for [pu] &[pju], British English

Looking at the F2 formant contours of the above graph, we are unable to infer any information about the palatal glide. Likewise, the Bulgarian and Russian SSANOVA graphs above do not give us any precise information about the palatal glide, be it a secondary or a primary gesture. We will, therefore, turn to representative spectrograms of all three languages for additional information.

Ladefoged and Maddieson (1996) note that, on a spectrogram, a palatal glide as a primary articulation is evident by the presence of a steady state portion associated with formants of the glide. Conversely, a glide as a secondary articulation lacks this steady state portion. Instead, the F2 formant contour forms a steep transition line, away from the consonant. Bilabial consonants are most suitable for our cross-language comparison as the tongue is not engaged in the formation of the primary consonantal gesture. Therefore, any formants present after the burst can be associated with the palatal gesture [5] (Ladefoged and Maddieson, 1996). Let us examine Ladefoged and Maddieson's criteria as we look at the following spectrograms.

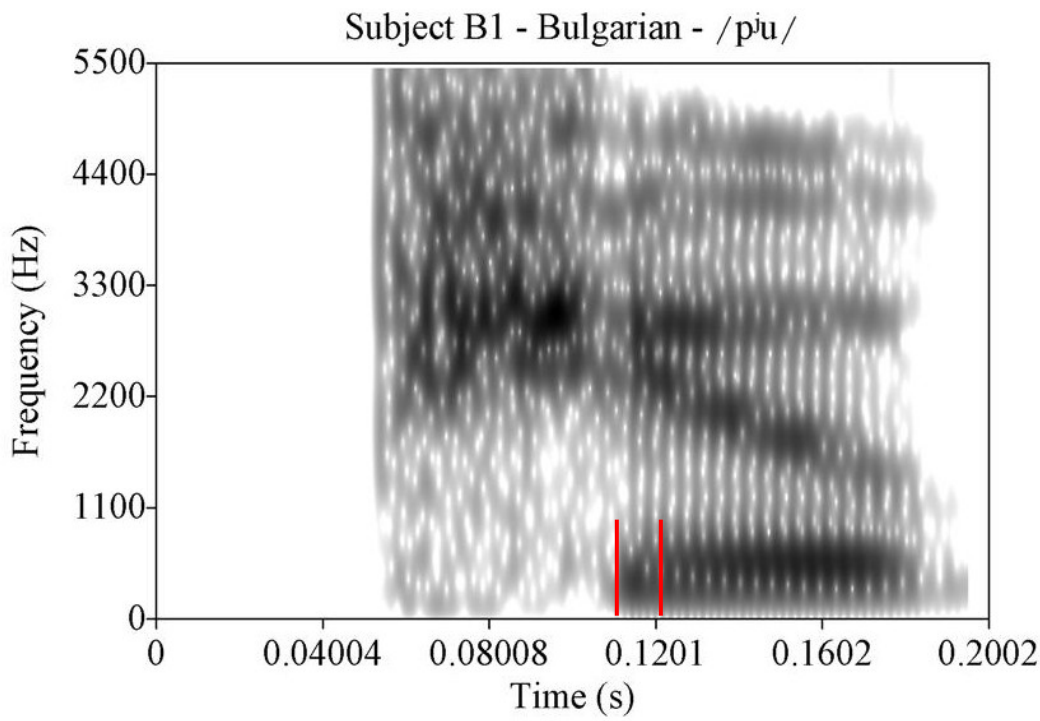

Figure 2.9a. Spectrogram of [pʲu]; Subject B1, Bulgarian

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[5] We should note that all formant values would lowered in the vicinity of a labial consonant, but palatalized labial consonants are still expected to have higher F2 formants, compared to their plain counterparts, due to palatalization.

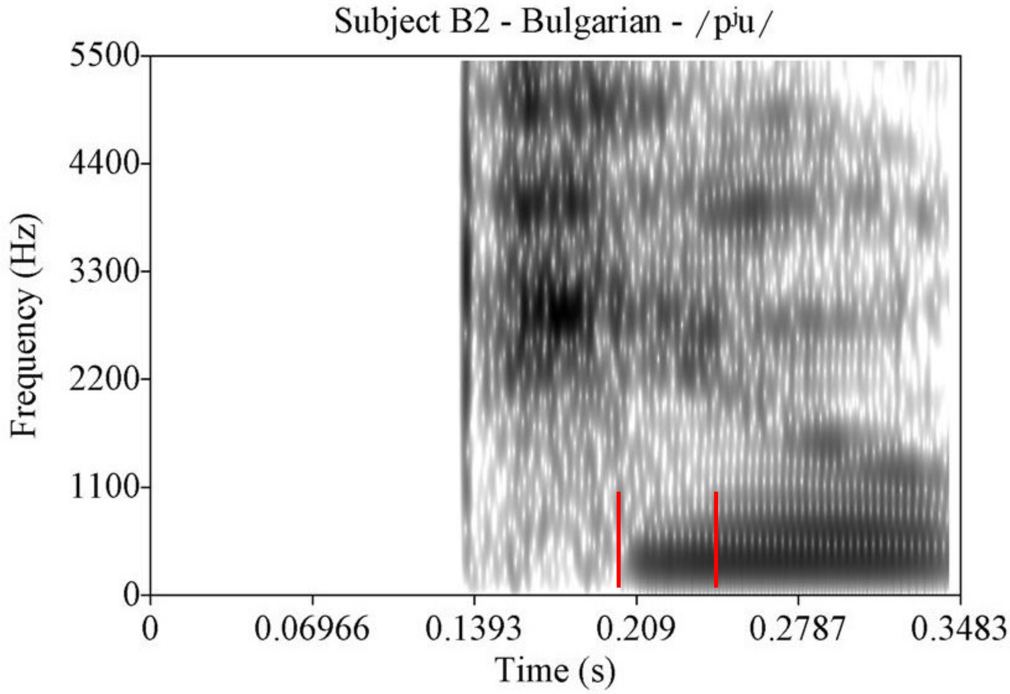

Figure 2.9b Spectrogram of [pʲu]; Subject B2, Bulgarian

On the first spectrogram (Figure. 2.9a), the transitions appear to slope steeply away from the consonantal portion. On the other one (Figure 2.9b), the transition slope is not as steep and a steady state portion is clearly visible. In the context of these spectrograms, Ladefoged and Maddieson's criteria appear ambiguous. In addition, their criteria are descriptive in nature.

One way to quantify these criteria is to measure the duration of the so called steady state portion, which is delineated in red, along the time axes of the spectrograms in Figures 2.9a and 2.9b. Specifically, the steady state portion was measured post the consonantal release and the period of aspiration, from the point of vocal fold vibration until the transitions with the following vowel begin. In addition, the delineated sound was listened to for a distinct [j] quality. If [ʲu] was heard, the boundary was moved to the left of the transitions until a distinct [ʲ] was heard. On average, the duration of the glide from the Bulgarian [pʲu] sequence was 0.03 seconds.

Let us turn to a representative Russian spectrogram (Figure 2.10) of the [pʲu] sequence and see if the steady state portion differs in any way. Comparable to Bulgarian, we can identify a short steady portion of the F2 formant associated with the palatal glide. The duration of this portion was measured. It was, on average, 0.02 seconds. Thus, in terms of the palatal glide, the Bulgarian and Russian spectra look alike. The duration of the glide is similar, 0.03 and 0.02 seconds, for Bulgarian and Russian, respectively. Furthermore, if we look at the overall contour of the F2 formants for both languages, they appear very similar and very much alike the F2 contours of the SSANOVA graphs.

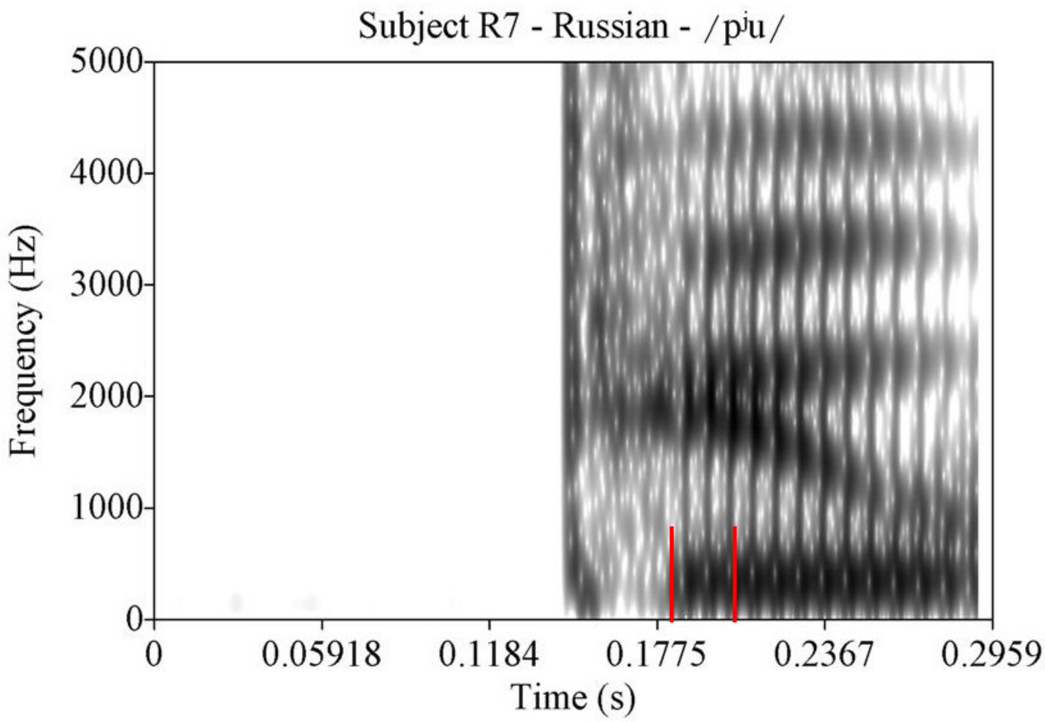

Figure 2.10. Spectrogram of [pʲu]; Subject R7, Russian

We would expect the British English palatal glide to have different spectral characteristics in comparison to the Bulgarian and Russian palatal glides. The representative spectrogram of the British [pju] sequence, Figure 2.11, has a clearly identifiable ‘steady state’ palatal glide portion. Even prior to measuring it, one could see that it is larger in duration, compared to Bulgarian and Russian. On average, its duration is 0.05 seconds. So, given the longer VOT of the English voiceless plosives, and the lengthier duration of the palatal glide, it is, perhaps, not surprising that the F2 formant contours on the [pu-pju] SSANOVA graphs of the British subjects reveal that the contrast is maintained for a longer duration (0.17 seconds, on average).

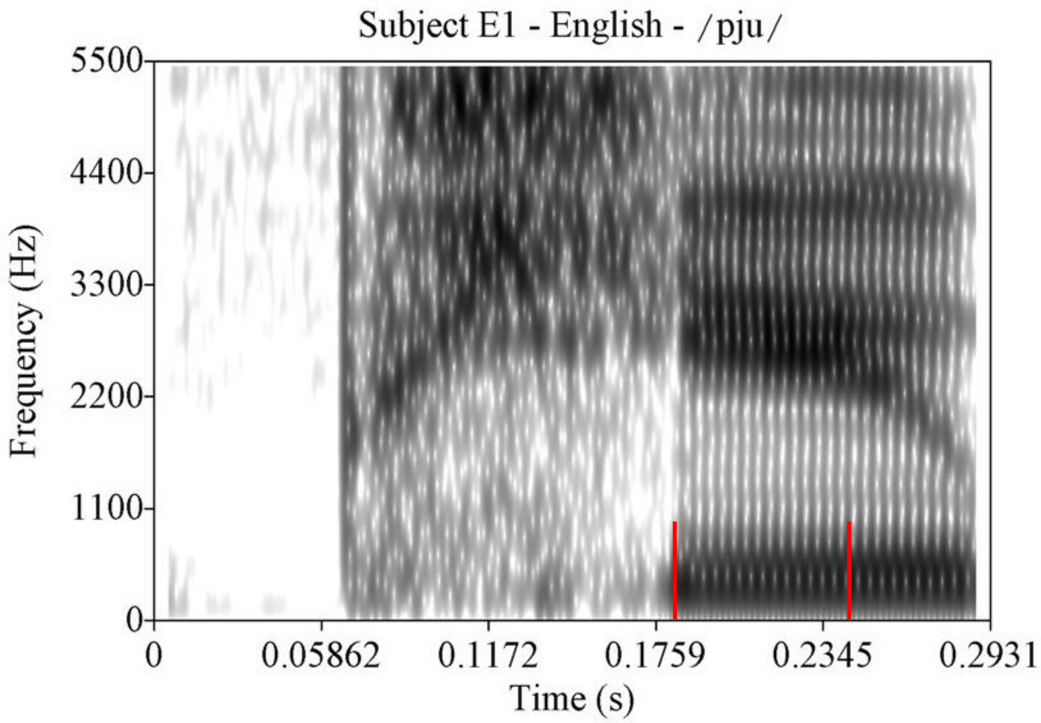

Figure 2.11 Spectrogram of [pju]; Subject E1, British English

In summary, the British palatal glide is longer in duration, compared to the Bulgarian and Russian ones. The measurements are summarized in the boxplots in Figure 2.12. The medians of the glide duration coincide with the averages. The data of the British subjects is skewed to the left. However, most scores are within the range of 0.05-0.06 seconds.

The Bulgarian data is also skewed to the left of the median. The Bulgarian and Russian scores fall between the same range, 0.02 and 0.03seconds, although the Bulgarian data is skewed to the left. It is likely that a larger group sample for all languages would yield a normally distributed data.

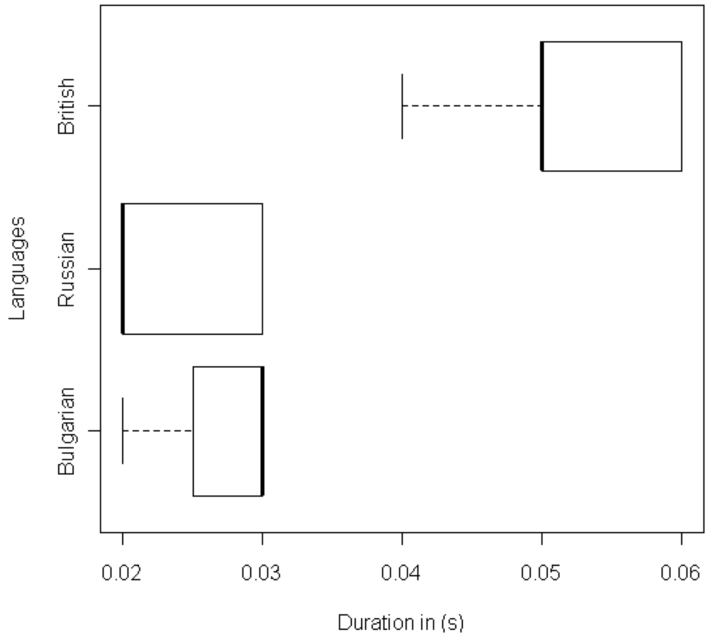

Figure 2.12. Boxplots of palatal glide duration across languages in the context of [p_u]

Next, we compare representative SSANOVA graphs of the [tju] and [kju] sequences, again across languages. The F2 contours of the Bulgarian and Russian [tju] sequence (Figures 2.13a and 2.13b) look very similar across subjects, and languages. On average, the confidence intervals of the F2 lines of [tu] and [tʲu] do not overlap for a period of 0.12 and 0.11 seconds for Bulgarian and Russian, respectively. The [tu – tʲu] contrast is clearly maintained for all subjects in both languages.

As it was the case with the [pju] contrast, the British [tju] contrast (Figure 2.13c) looks very different from the Bulgarian and Russian ones. Again, the part of the contour preceding the transition to the following vowel is much longer in duration. Given the similarities between the British [pju] and [tju] F2 formant contours, it is reasonable to assume a longer VOT time and a longer duration of the palatal glide. For three of the British subjects, the [tu – tju] sequences remain different for an average period of 0.19 seconds (Figure 2.13c), before their confidence intervals overlap. The [pu – pju] sequences of the British subjects remain different for a similar average duration of 0.18 seconds. The other five subjects' [tu – tju] F2 formant contours never overlap, suggesting that the F2 frequencies of the vowel following the palatal glide are higher than those of the vowel following the plain consonant.

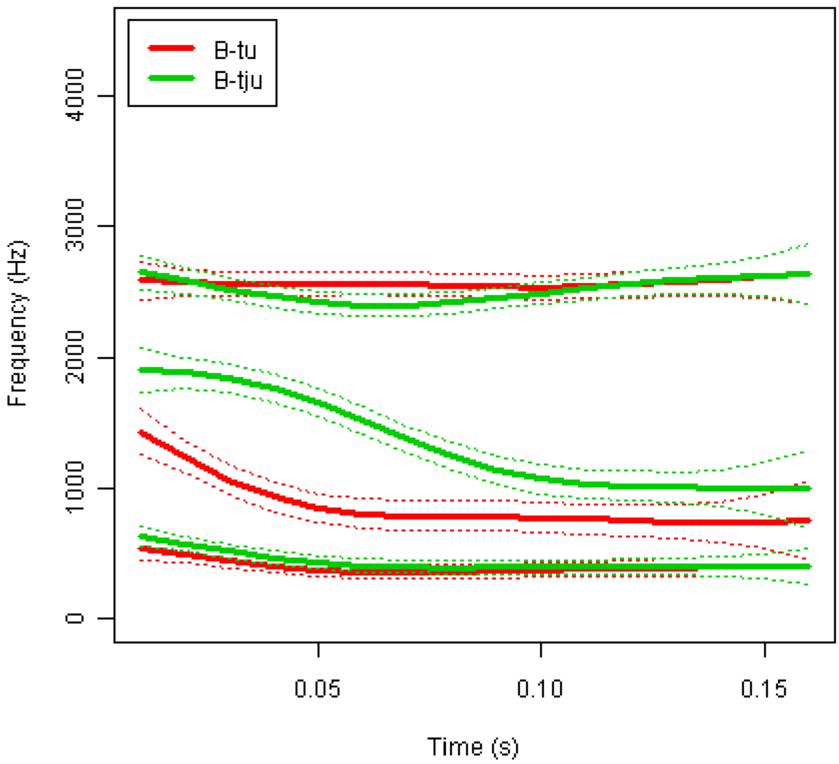

Figure 2.13a SSANOVA graph for [tu] & [tʲu], Bulgarian

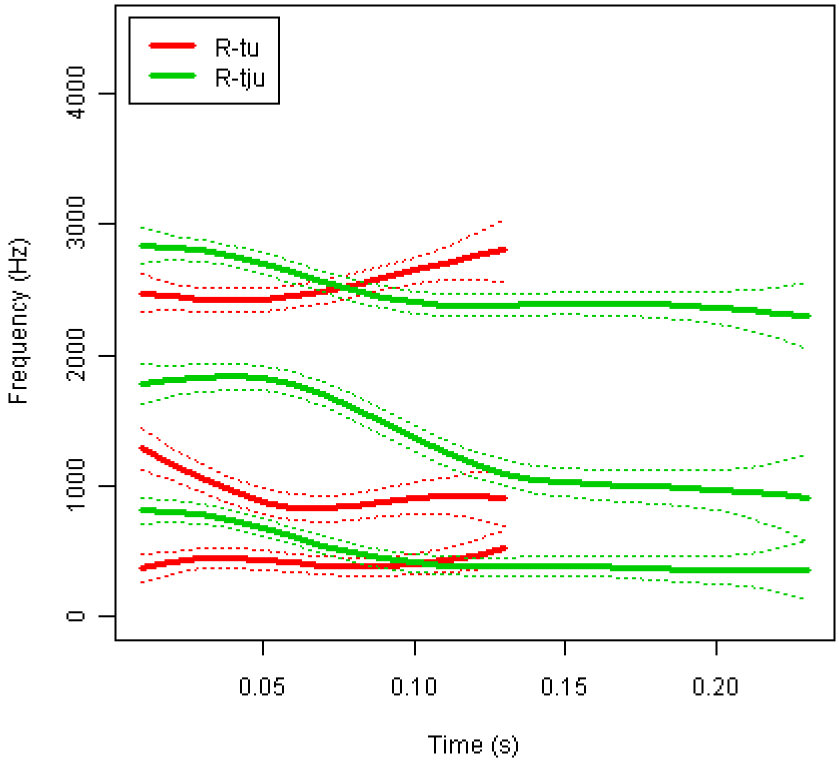

Figure 2.13b SSANOVA graph for [tu] & [tʲu], Russian

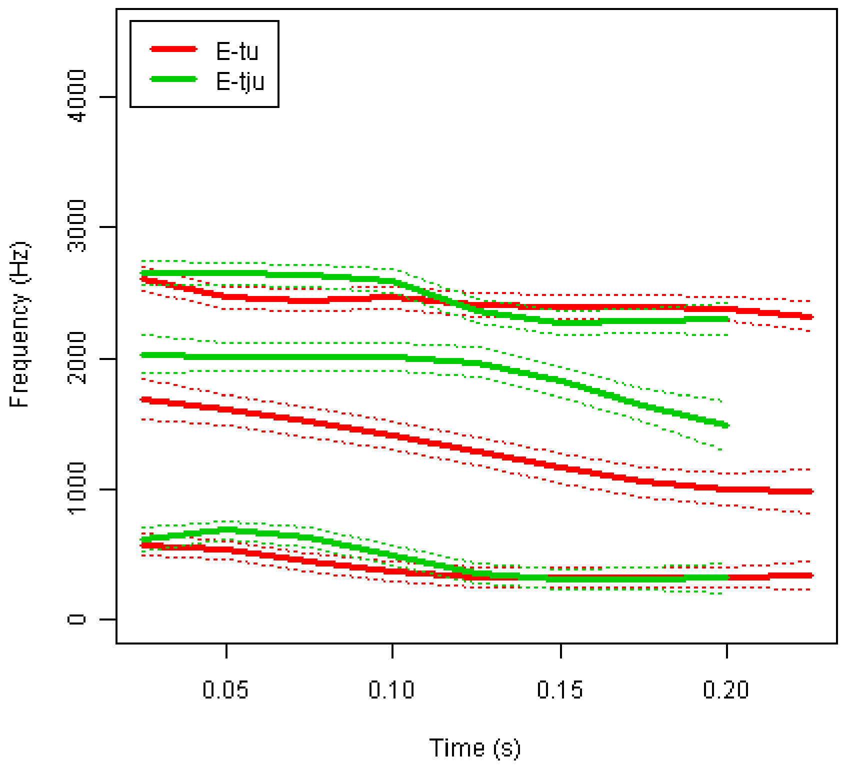

Figure 2.13c SSANOVA graph for[tu] & [tju], British English

The boxplots in Figure 2.13d represent individual averages of the duration during which the [tu-tju] contrast is maintained in Bulgarian, Russian and British. The averages are computed by the SSANOVA algorithm which attempts to find the best fit for the data. There is a larger variability of averages in the Russian data. However, both languages have the same median of 0.12 seconds. The scores for the British data fall between the range of 0.18 and 0.20 seconds. Recall that only the data of three subjects were included in this comparison, as for the remainder of the subjects the contrast remained throughout the entire duration of the sequences.

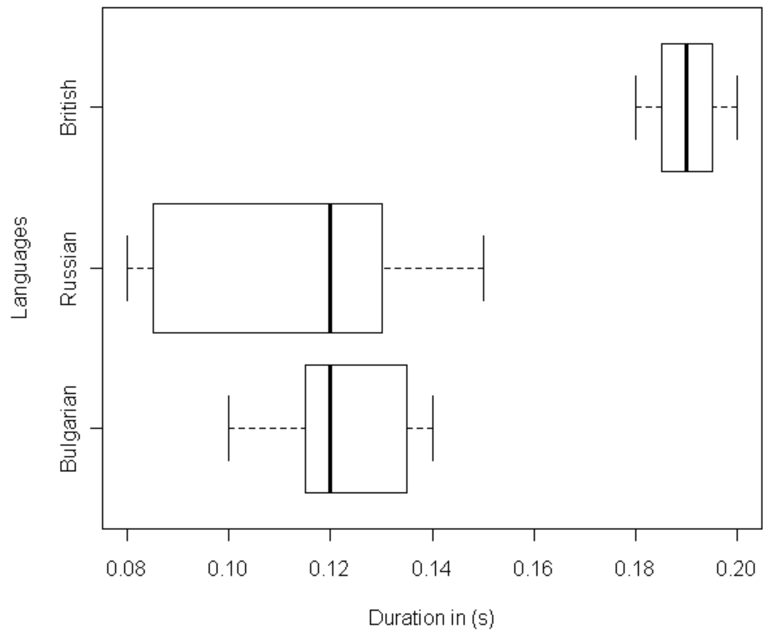

Figure 2.13d Boxplots of the duration of formant contours for the [tu-tju] contrast, prior to overlapping

The situation with the [ku] vs. [kju] contrast is reminiscent of that for the contrasts of the voiceless plosives discussed so far. This applies to the all three languages, with British English standing apart from Bulgarian and Russian. Therefore, no SSANOVA graphs of the [ku]-[kju] contrast are displayed. We note that the contrast is maintained for an average duration of 0.09 and 0.10 seconds, for Bulgarian and Russian, respectively. The average duration for British English comes to 0.17 seconds. The range of individual averages across languages is illustrated in the boxplots of Figure 2.14. Comparable to the previous voiceless plosives, the British data is spread along the high end of the time scale.

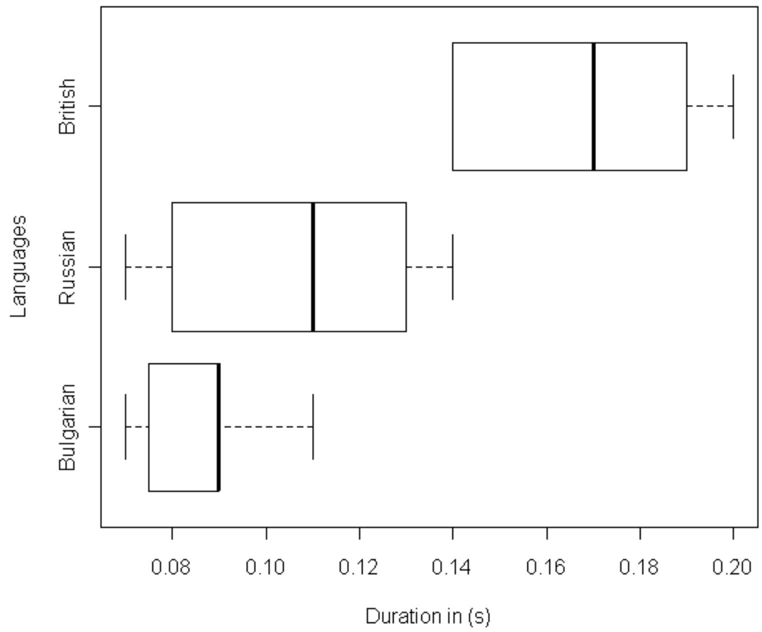

Figure 2.14 Boxplots of the duration of formant contours for the [ku-kju] contrast, prior to overlapping

Next we look at the voiced plosive consonants, beginning with the [bu] and [bju] sequences. Figures 2.15a and 2.15b show representative SSANOVA graphs for the Bulgarian and Russian data. The SSANOVA statistics for the Bulgarian and Russian data indicate unambiguously that the contrast is maintained in both languages. The F2 contours of these sequences remain distinct for an average duration of 0.10 seconds. British English (Figure 2.15c) stands apart from Bulgarian and Russian in that the F2 [bju] contour is longer prior to the transitions slope. The boxplots in Figure 2.16 illustrate the distribution of individual averages within each language. Bulgarian and Russian have similar range of scores which indicate that the [bu-bju] contrast is maintained for nearly the same amount of time.

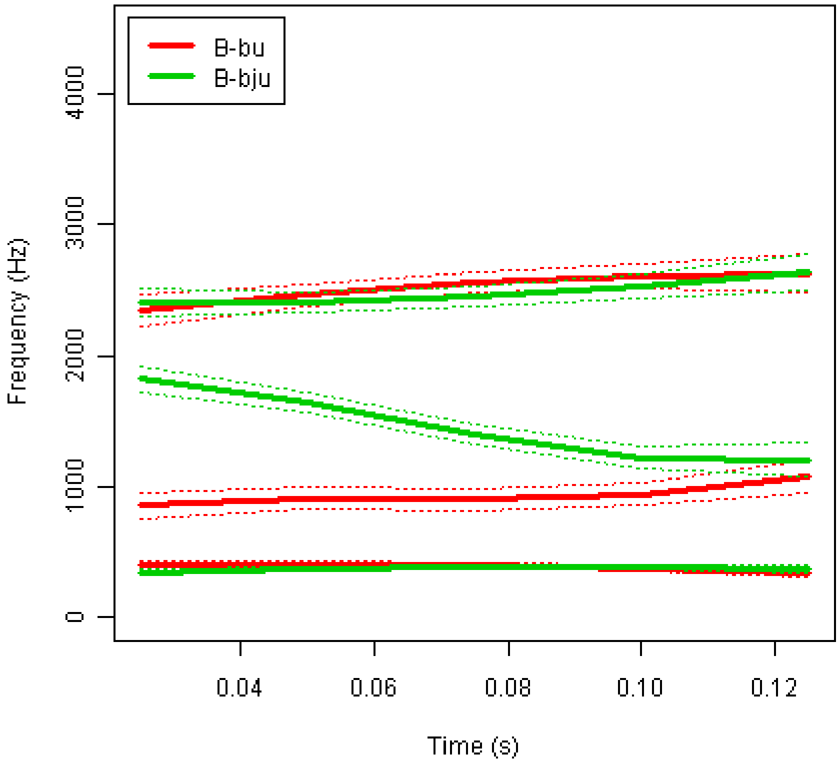

Figure 2.15a SSANOVA graph for [bu] &[bʲu], Bulgarian

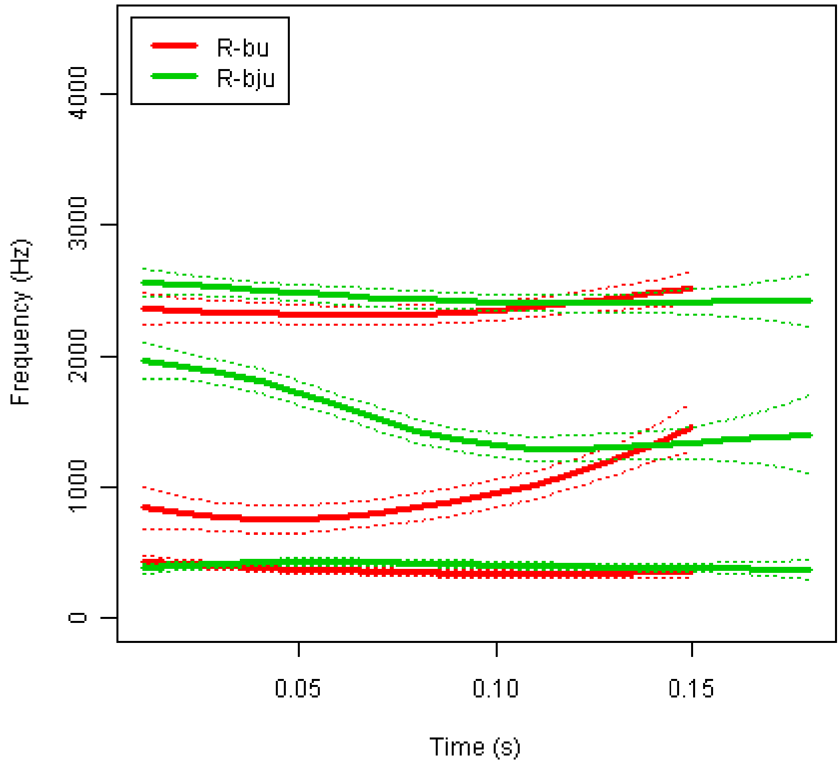

Figure 2.15b SSANOVA graph for [bu] & [bʲu], Russian

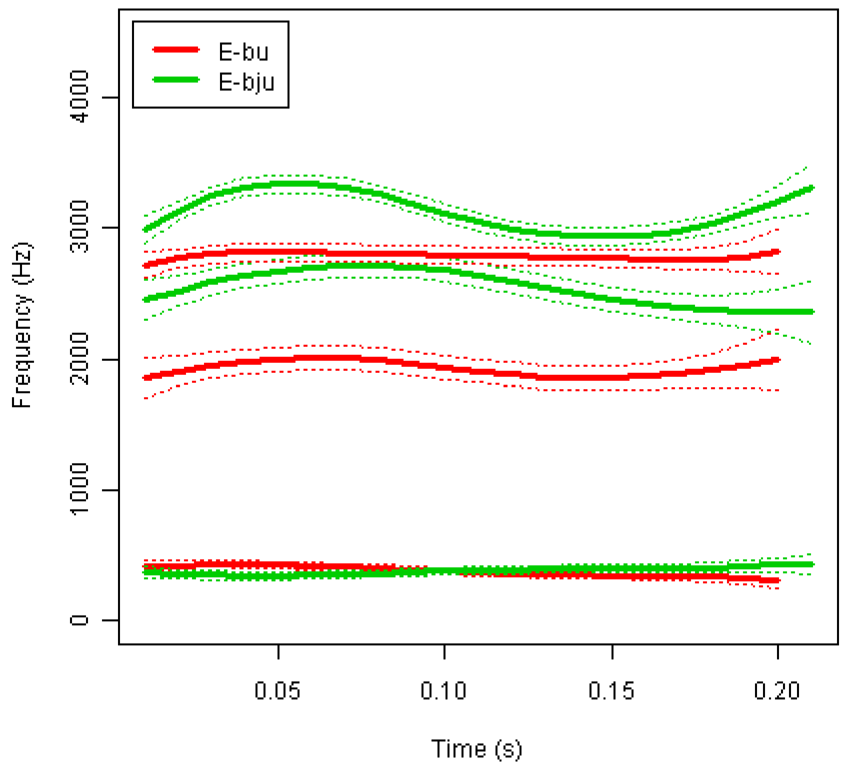

Figure 2.15c SSANOVA graph for [bu] & [bju], British English

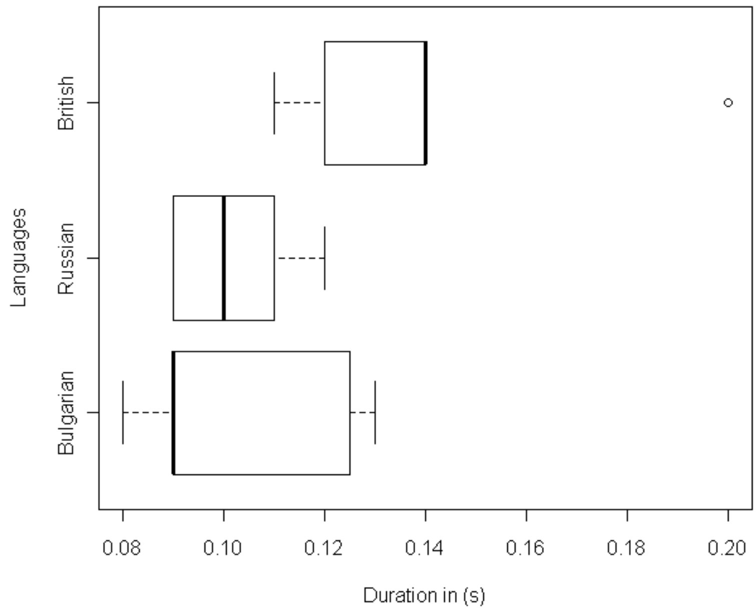

Figure 2.16 Boxplots of the duration of formant contour for the [bu-bju] contrast, prior to overlapping

As we mentioned before, the tongue is not involved in the primary articulation of bilabial consonants. Thus, any formants present after the release of the consonants may be associated with the following palatal glide, be it a primary or a secondary gesture. The spectrograms below are representative of the Bulgarian (Figure 2.17a), Russian (Figure 2.17b) and British (Figure 2.17c) data. There is an identifiable steady state glide portion in the spectra of the Bulgarian and Russian [b^{j}u] sequence. The average duration of the glide in the [b_u] context is 0.04 seconds. The duration of the British palatal glide steady state portion is longer than that of the Bulgarian and Russian, 0.08 seconds. As more data accumulates, it is becoming obvious that the Bulgarian palatal glide is more like the Russian, than the British palatal glide. The boxplots in Figure 2.18 further illustrate this similarity. Both languages have a similar range of scores, with a median of 0.04 seconds. The scores for the 8 British subjects range from 0.07 to 0.09 seconds. It is important to note that, the lack of aspiration post the release of [b], allows for more direct comparisons across the three languages. Our data indicates that the duration of the palatal glide as a secondary gesture is shorter than the duration of the palatal glide as a primary gesture.

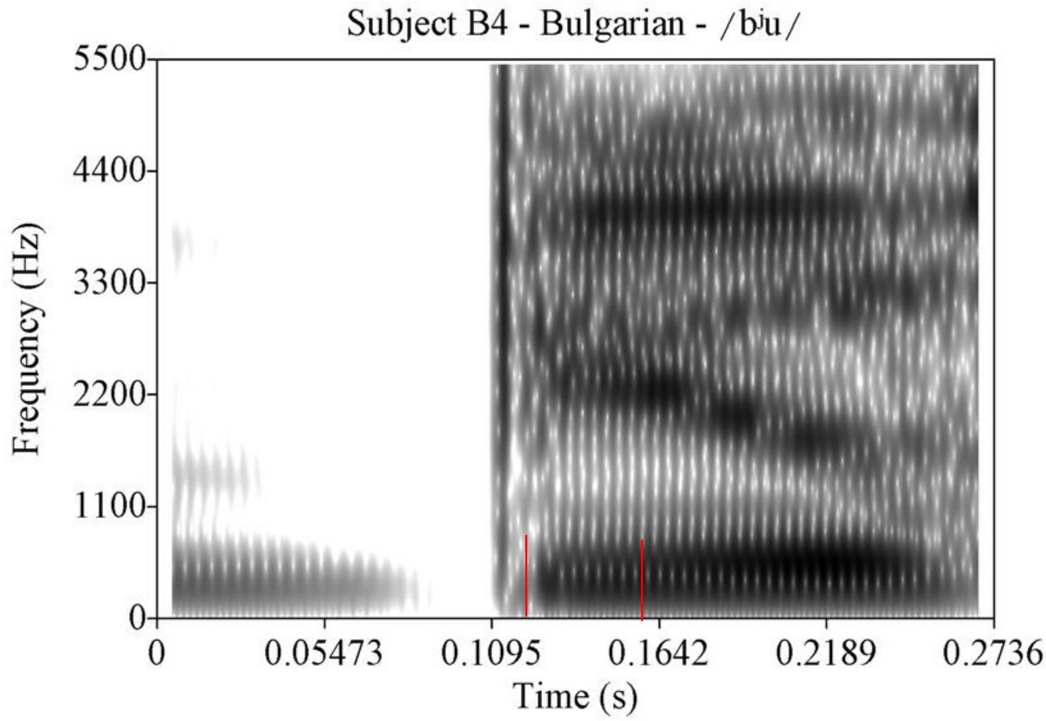

Figure 2.17a Spectrogram of [bʲu]; Subject B1, Bulgarian

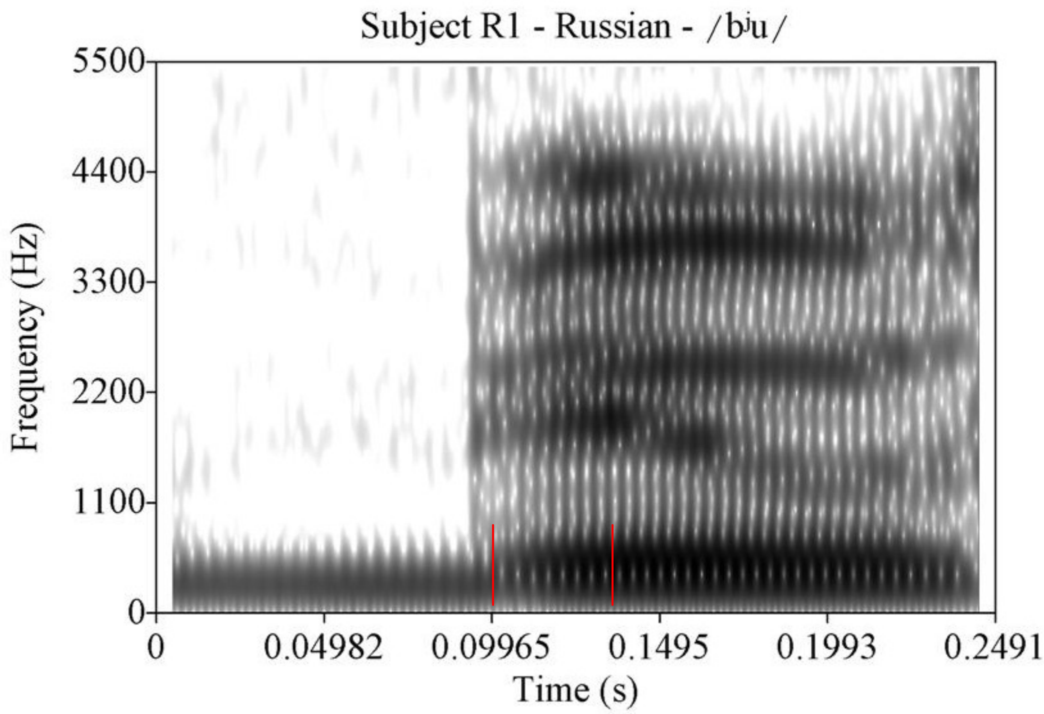

Figure 2.17b Spectrogram of [bʲu]; Subject R1, Russian

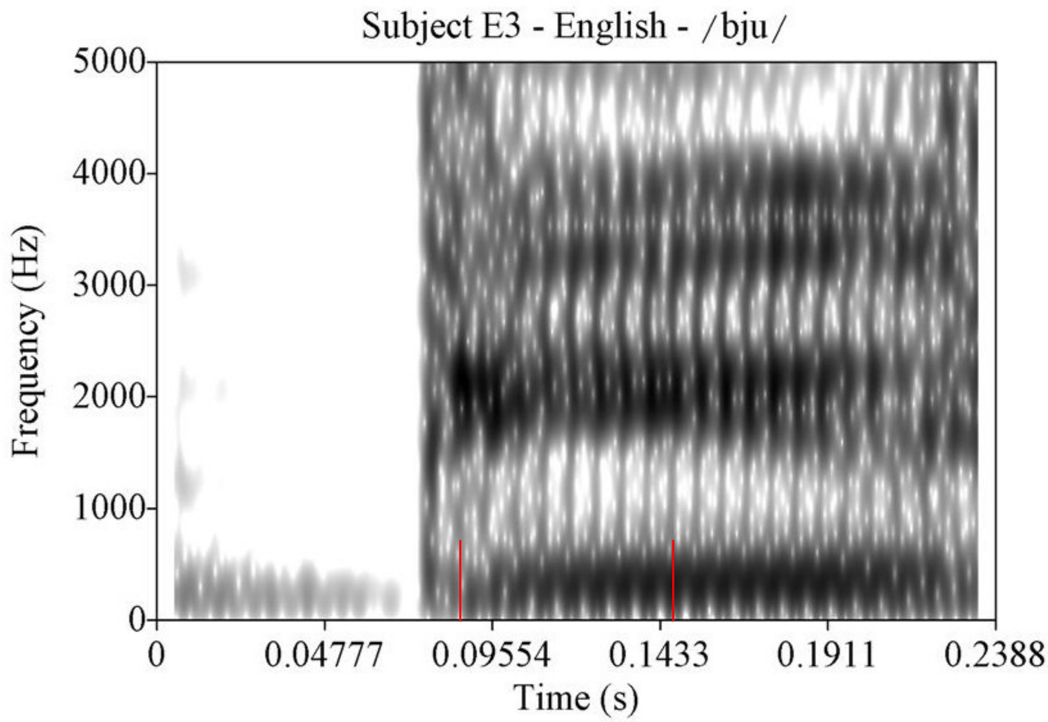

Figure 2.17c Spectrogram of [bju]; Subject E3, British English

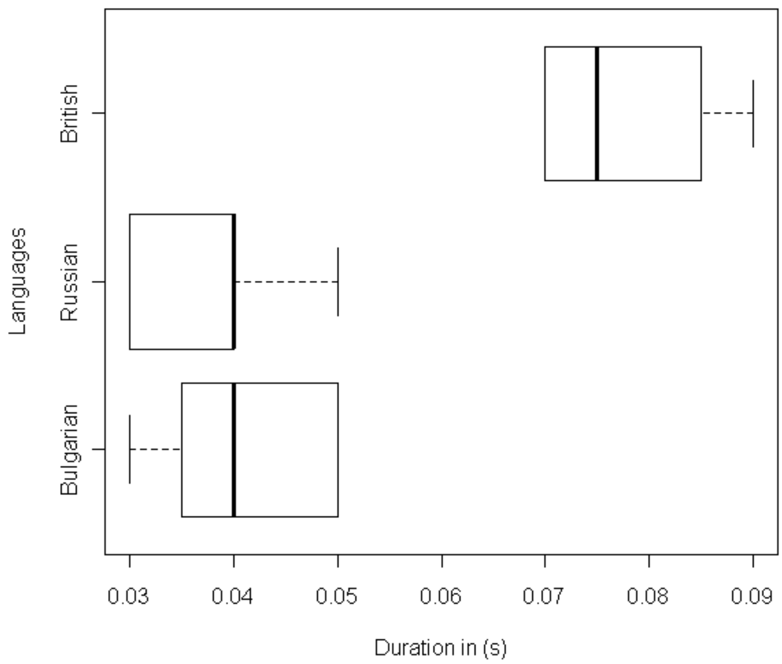

Figure 2.18 Boxplots of palatal glide duration across languages in the context of [b_u]

So far, the data from the spectrograms and the SSANOVA statistics have indicated that the Bulgarian palatal glide is more like the Russian than the British palatal glide. This is certainly true in the context of the back vowel [u]. However, soft consonants appear before the vowel [a] in both Russian and Bulgarian. Next, we look briefly at representative SSANOVA graphs of the [pa – pja] contrast, (Figures 2.19a and 2.19b.

According to the SSANOVA F2 formant contours of the plain and palatalized sequences, both languages maintain the [pa-pja] contrast. Apart from subject B8, the F2 lines of the Bulgarian subjects remain apart until the confidence intervals overlap at 0.12 seconds, on average. The overlap appears to occur at the level of the vowel [a]. The inference is that the F2 of [a] from both sequences occurs along similar frequencies. The most striking feature of the F2 contours of the Russian [pa-pja] contrast is that the lines remain apart throughout the entire duration, for all subjects. The palatal segment in the [pja] sequence raises the vowel frequencies to the extent that they are much higher than those of the [a] in the [pa] sequence. The representative spectrograms in Figures 2.20a and 2.20b show the same trend of the F2 formant. We notice that the frequencies of the Russian [a] are around 2000Hz; the frequencies of the Bulgarian [a] are around 1200Hz. In the palatal glide context, the Russian vowel has higher F2 frequency. When the palatal glide is absent, both the Russian and Bulgarian [a] has an F2 around 1100 Hz. An F2 increase is usually associated with the narrowing of the frontal cavity. We will come back to this issue again in the discussion section.

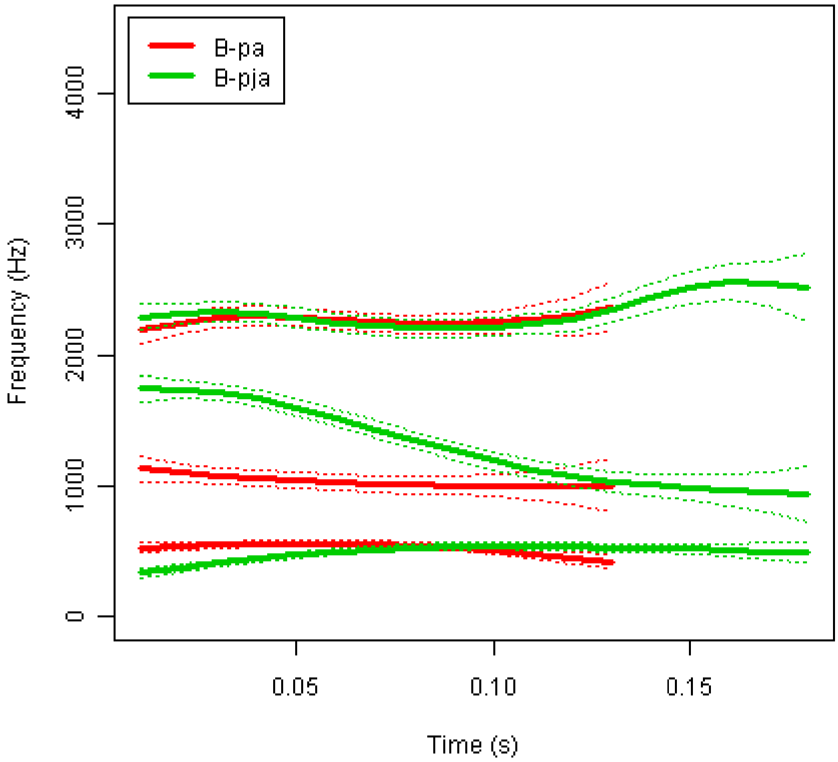

Figure 2.19a SSANOVA graph for [pa] & [pʲa], Bulgarian

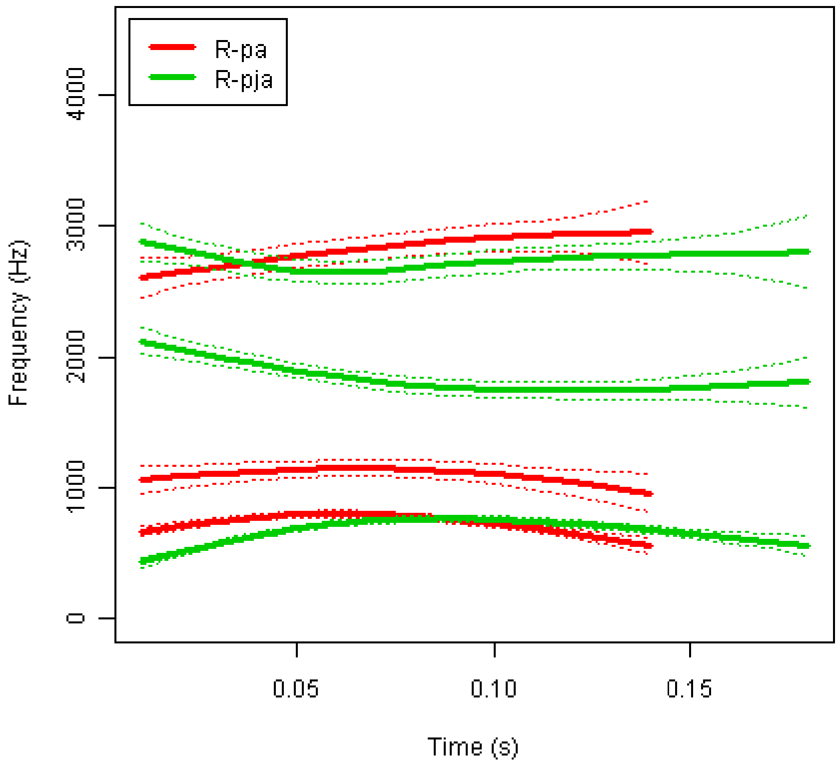

Figure 2.19b SSANOVA graph for [pa] & [pʲa], Russian

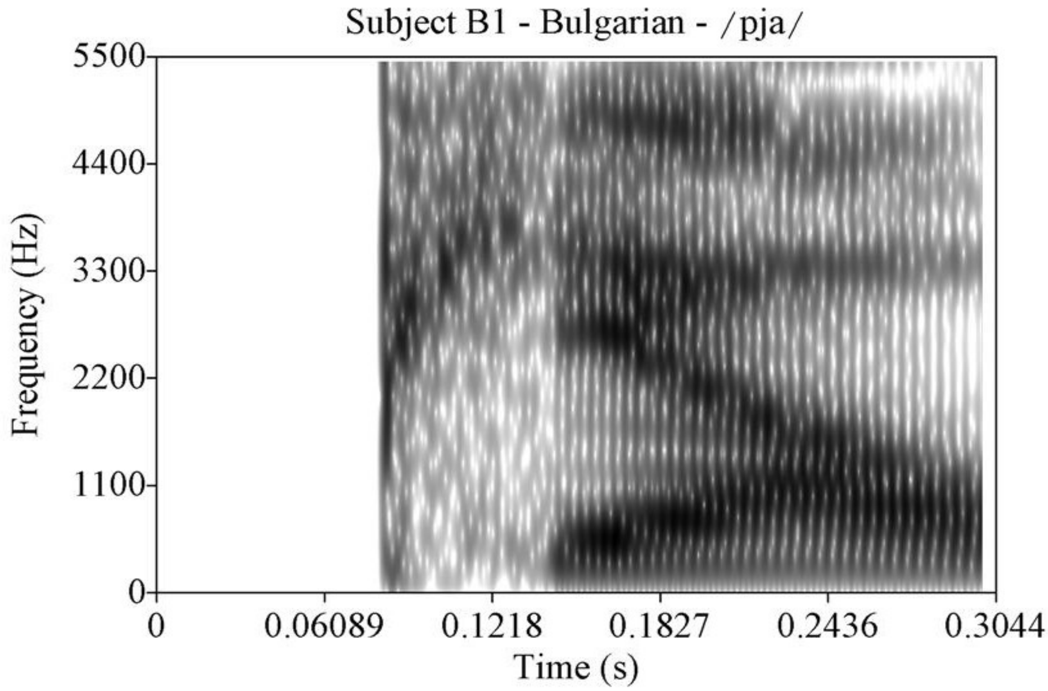

Figure 2.20a Spectrogram of the Bulgarian [pʲa] sequence

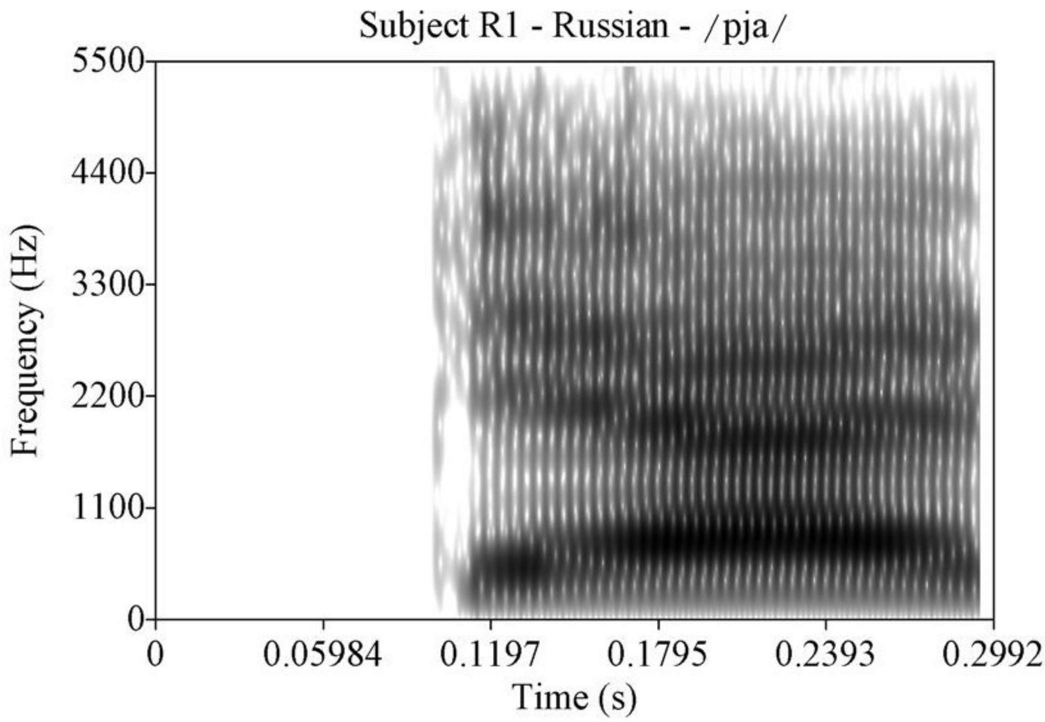

Figure 2.20b Spectrogram of Russian [pʲa] sequence

Although the SSANOVA [pa-p^{j}a] graphs show that the contrast exists in both languages, they tell us nothing about the nature of the palatal glide element. As[p] is a bilabial consonant, its primary articulation does not involve the tongue. According to Ladefoged and Maddieson (1996), any formants present post the release of the consonant can be associated with the palatal glide. The boxplots in Figure 3.21 represent scores obtained from measurements of the duration of the steady formants of the palatal glide from spectrograms from both languages. As the plots illustrate, the averages span across the same range for both languages. The medians are the same as the averages for both data sets. On average, the duration of the steady glide formants is 0.03 seconds for both languages. Thus, in terms of these measures, the Bulgarian palatal glide is similar to the Russian one.

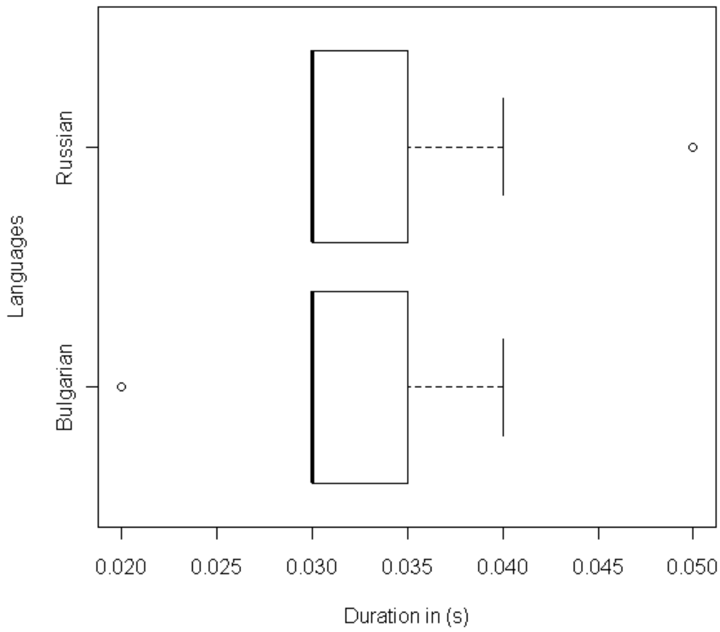

Figure 2.21. Boxplots of palatal glide duration across languages in the context of [p_a]

We will now briefly examine representative SSANOVA graphs of the voiced counterparts [ba-bja], Figure 2.22a (Bulgarian) and Figure 2.22b (Russian) below.

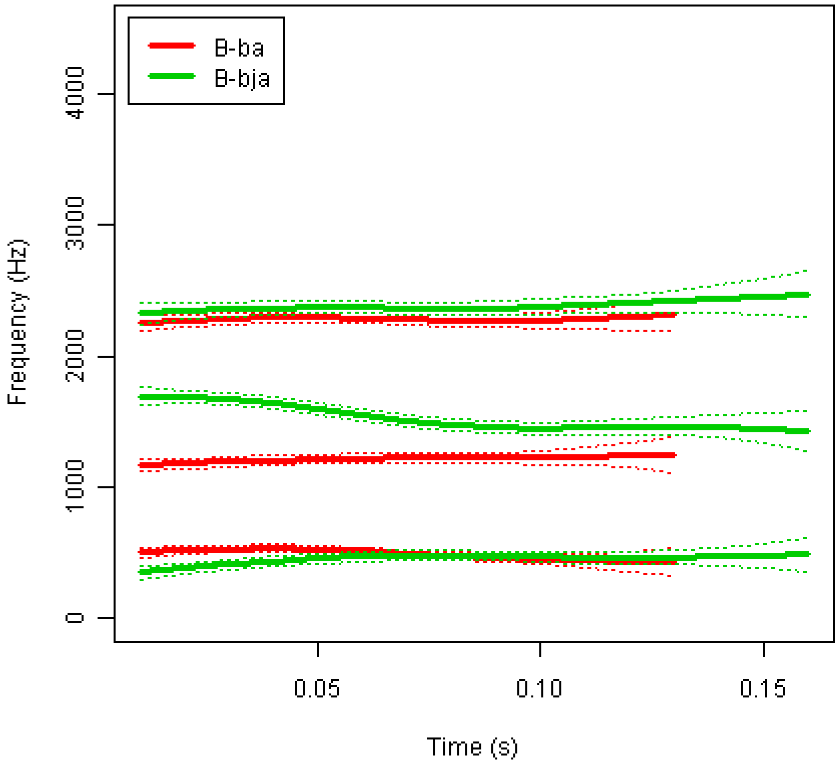

Figure 2.22a SSANOVA graph for [ba] & [bʲa], Bulgarian

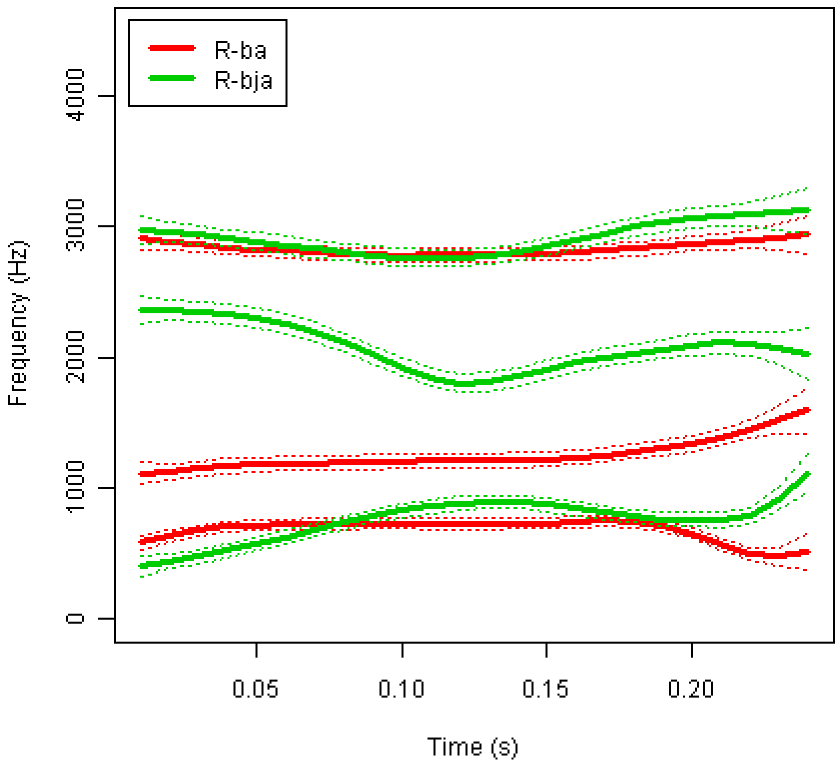

Figure 2.22b SSANOVA graph for [ba] & [bʲa], Russian

The SSANOVA graphs indicate that the contrast is maintained in both languages. On average, the confidence intervals of the Bulgarian F2 [ba-b^{j}a] contours overlap at 0.13s. As with the [pa-p^{j}a] contrast, the Russian SSANOVA [ba-b^{j}a] graphs differ from the Bulgarian graphs in that the F2 contours of the plain and palatal sequences do not come together for all but one subject (R4). We will not dwell on this difference here but will come back to it in the discussion section.

Recall that the advantage of measuring the acoustic attributes of the bilabial palatalized stops is that any formants following their release can be attributed to the palatal glide, be it a primary or a secondary gesture. We established that the duration of the steady state formants of the palatal segment in [pja] was an average of 0.03 seconds for both Bulgarian and Russian. The duration of the palatal segment in [bja] is 0.04 seconds, on average, again for both languages, Figure 2.23. The boxplots are skewed to the left for Russian and to the right for Bulgarian. A larger sample of subjects is likely to produce a more normally distributed population of scores.

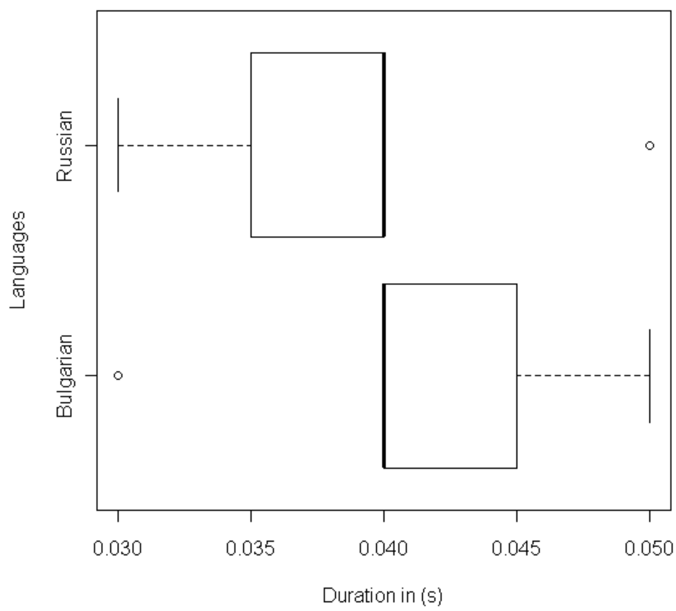

Figure 2.23 Boxplots of palatal glide duration across languages in the context of [b_a]

In summary, according to the SSANOVA statistics, there is a difference between the Bulgarian and Russian F2 [pja] and [bja] contours. It is interesting that, compared to Bulgarian, the vowel [a] from the Russian palatal sequence has F2 frequency similar to those of the palatal segment. However, the two languages have identical average glide duration, 0.03 and 0.04 seconds, for the voiceless and voiced bilabial consonant, respectively. We will now look at the [ta-tʲa] and [da-dʲa] contrasts to establish if the contrasts exists across the languages. Below are representative SSANOVA graphs of the [ta-tʲa] contrast for Bulgarian (Figure 2.24a) and Russian (Figure 2.24b).

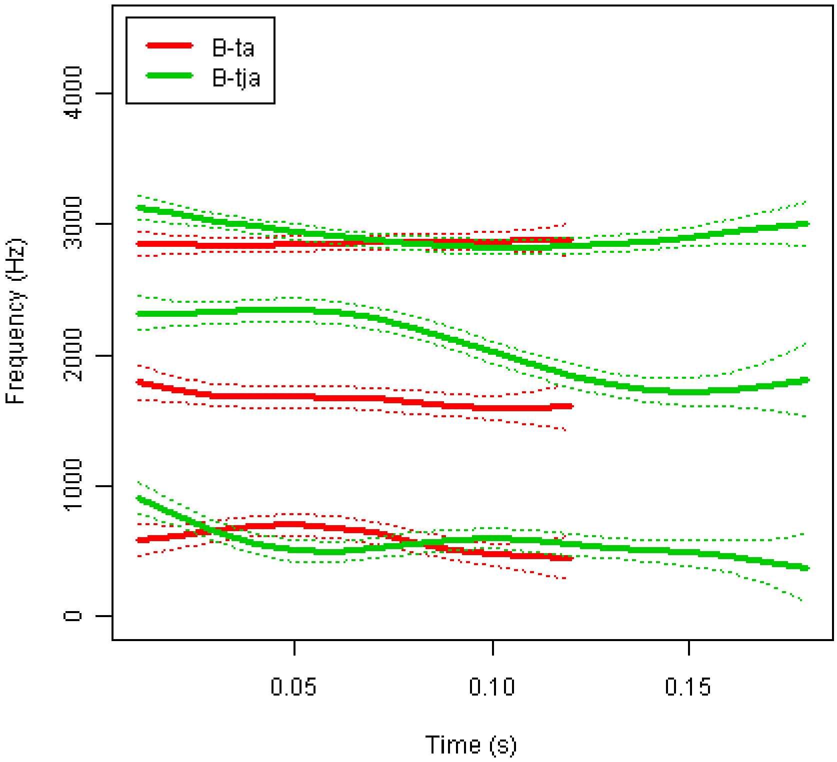

Figure 2.24a SSANOVA graph for [ta] & [tʲa], Bulgarian.

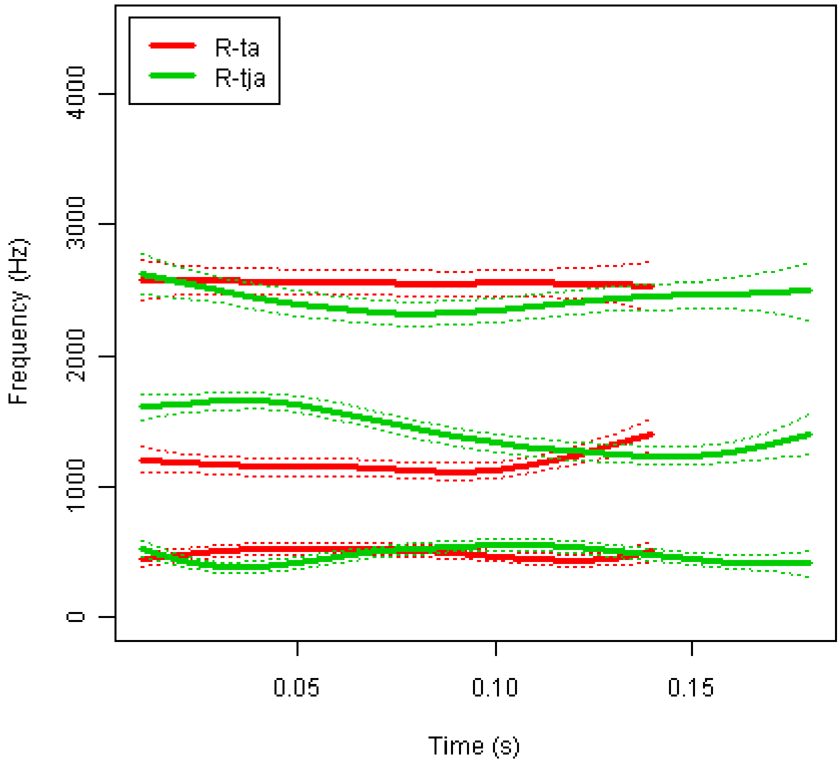

Figure 2.24b. SSANOVA graph for [ta] & [tʲa], Russian.

The SSANOVA graphs for the [ta] and [tʲa] segmental sequences appear identical for the Bulgarian and Russian subjects. The contrast is clearly present in both languages. The F2 contours for the palatal sequence begins with a transition away from the consonantal release, a brief steady portion of the glide, followed by a transition slope towards the vowel [a]. The F2 confidence intervals of the plain and palatal sequences overlap towards the end of the transition curve and the beginning of the following vowel. Unlike the vowel [a] of the palatalized bilabial segmental sequences, the [a] in the above graphs appears to have similar F2 frequency for both the plain and palatal sequences, for both languages. The intersection of the confidence lines occurs around 0.12 seconds, on average, for Bulgarian and Russian. The boxplots in Figure 2.25 show the duration of formant contours prior to overlapping, across languages, as calculated by the SSANOVA. The medians differ between languages, 0.11 and 0.13 seconds, for

Bulgarian and Russian, respectively. It is likely that a larger sample of subjects would yield a more normal distribution of scores.

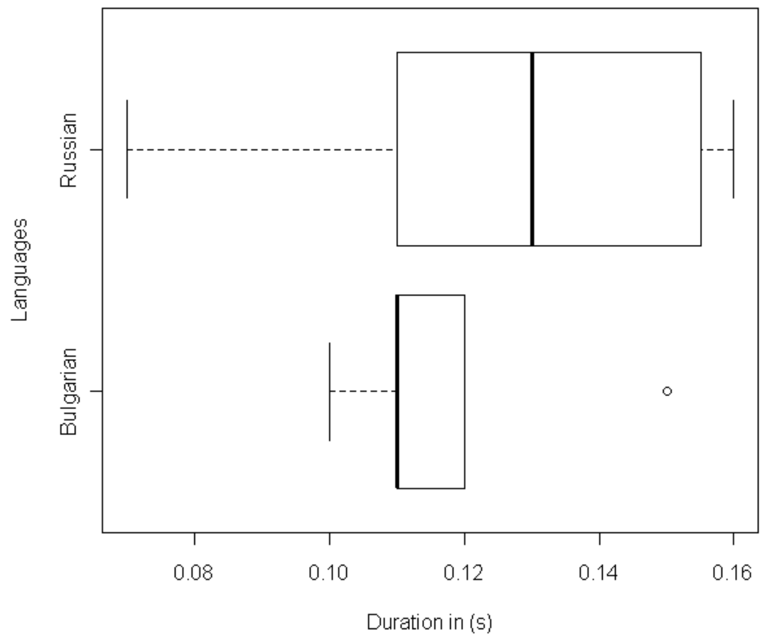

Figure 2.25. Boxplots of the duration of formant contours for the [ta-tʲa] contrast, prior to overlapping

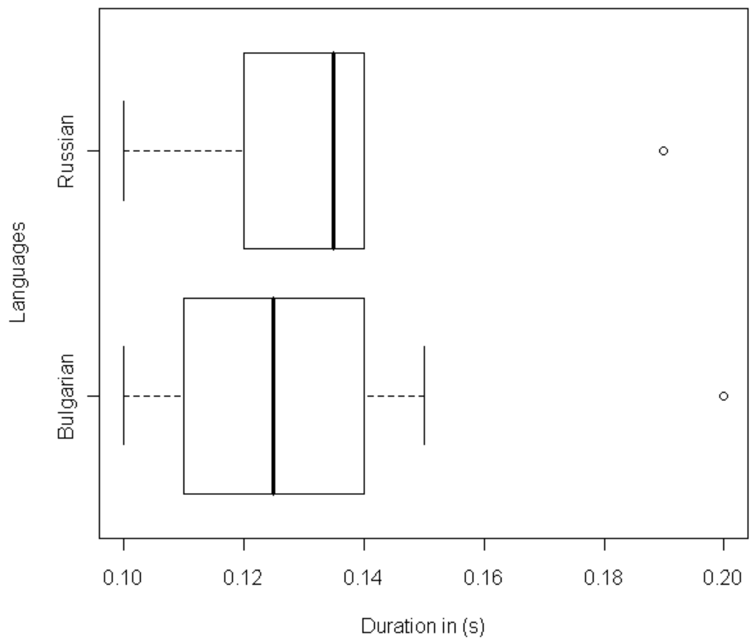

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Figure 2.26 Boxplots of the duration of formant contours for the [da-tʲa] contrast, prior to overlapping

The SSANOVA graphs for the [da-dʲa] contrast appear identical for both languages. They also look similar to those of the [ta-tʲa] contrast. Therefore, we will not discuss them here. In the boxplots of Figure 2.26 we could see the duration of the formant contours prior to the point of overlap. The medians are 0.125 and 0.135 seconds for Bulgarian and Russian, respectively. Both languages have a similar range of scores.

The SSANOVAs for the velar voiceless [ka-kja] and voiced [ga-gja] segmental sequences are similar for Bulgarian and Russian. They are also very similar to the other plosives in the context of [Cja]. Therefore, we will not show them here. The contrast is clearly maintained and the F2 formant contours overlap at an average of 0.10 and 0.12 seconds for the [ka-kja] and [ga-gja], respectively, for both languages. The vowel [a] from the palatalized sequences does not have F2 frequencies as high as those of the palatal glide, unlike the vowel [a] in the palatalized bilabial voiced and voiceless sequences.

2.4.2 Plain and Palatalized Fricative Consonant Contrasts in the context of of the vowels [u a]

As can be seen from the representative SSANOVA graph in Figure 2.27a, the [fu-fju] contrast is maintained in British English. The British F2 contour of the [fju] segmental sequence begins with a steady state portion, after which the transitions with the following vowel begin. The steady state period is most likely associated with the palatal glide. The contrast is also present in Bulgarian and Russian, as indicated by the representative SSANOVA graphs in Figures 2.27b and 2.27c (Bulgarian) and Figure 2.27d (Russian). The F2 contours of the segments in those graphs are distinct for a period of 0.10 seconds, on average, for all Russian subjects, and 4 Bulgarian subjects (as in

Figure 2.27b), after which the confidence intervals overlap at the level of the vowel. For the remainder of the Bulgarian subjects the F2 contours of the plain and palatal sequences remain apart (as in Figure 2. 27c). What is noticeably different in the F2 contours of the [fju] sequences of Bulgarian and Russian, in comparison to British English, is the absence of the steady state portion. Furthermore, the F1 contours overlap with no significant difference in all three languages, which indicates that the palatal segment does not affect those frequencies. The F3 contours show more variability, which possibly reflects individual differences (Ladefoged, 1993).

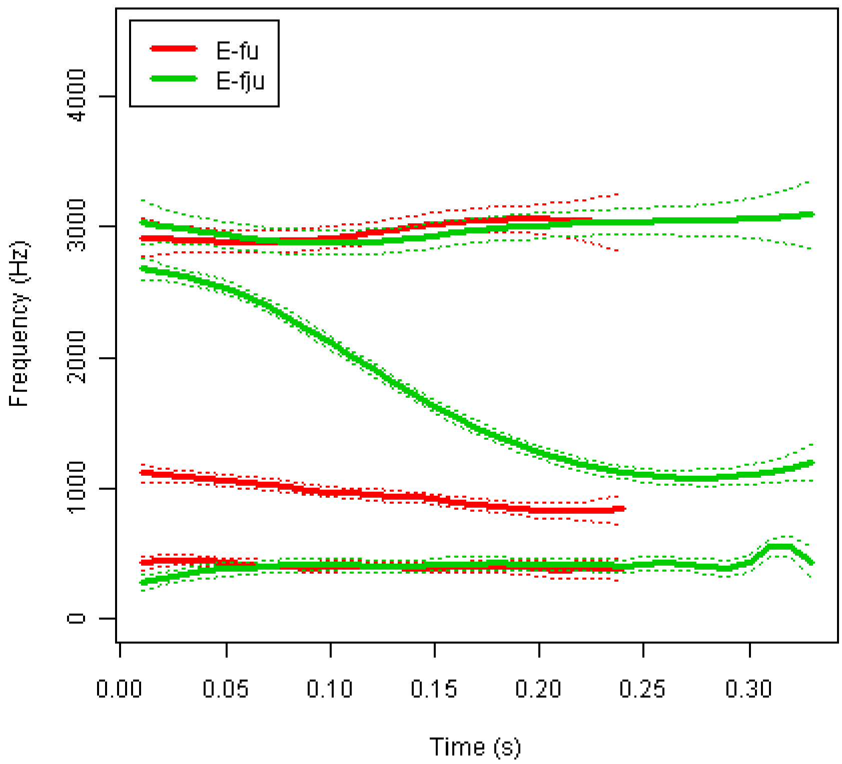


Figure 2.27a SSANOVA graph for [fu] & [fju], British English

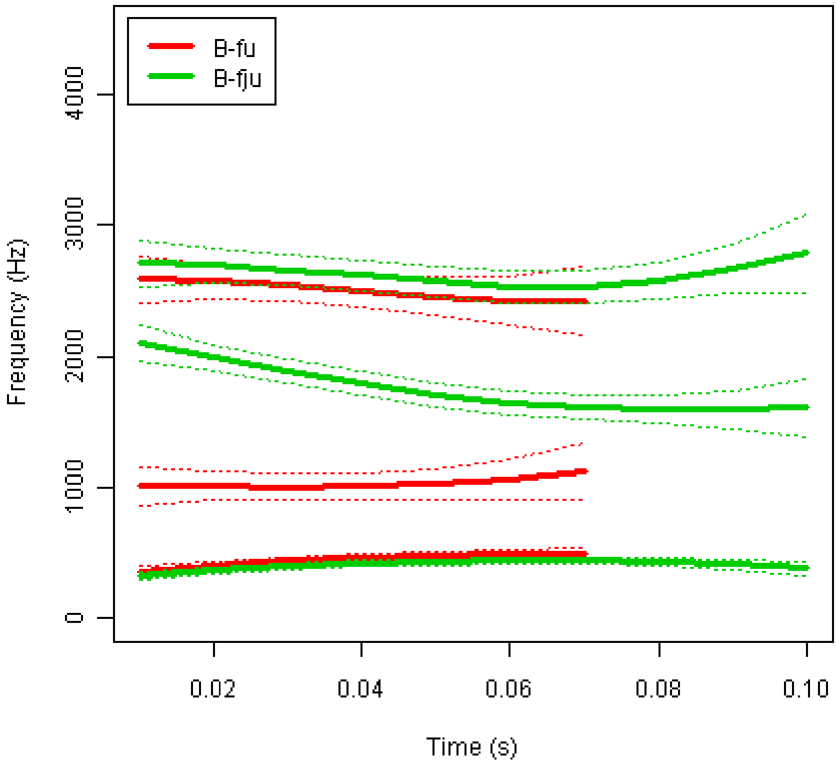


Figure 2.27b SSANOVA graph for [fu] & [fʲu], Bulgarian

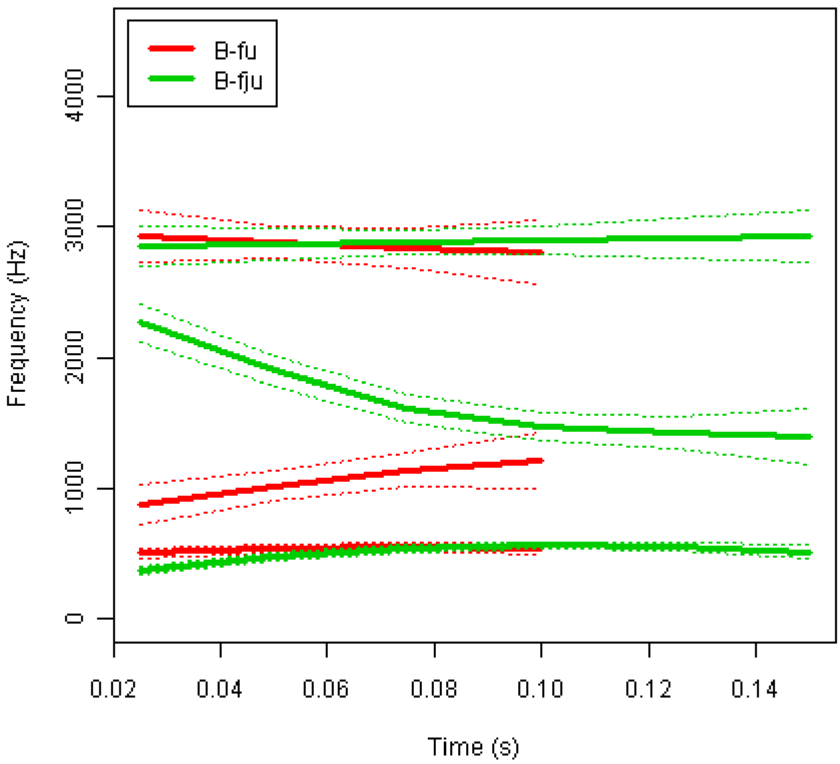


Figure 2.27c SSANOVA graph for [fu] & [fʲu], Bulgarian

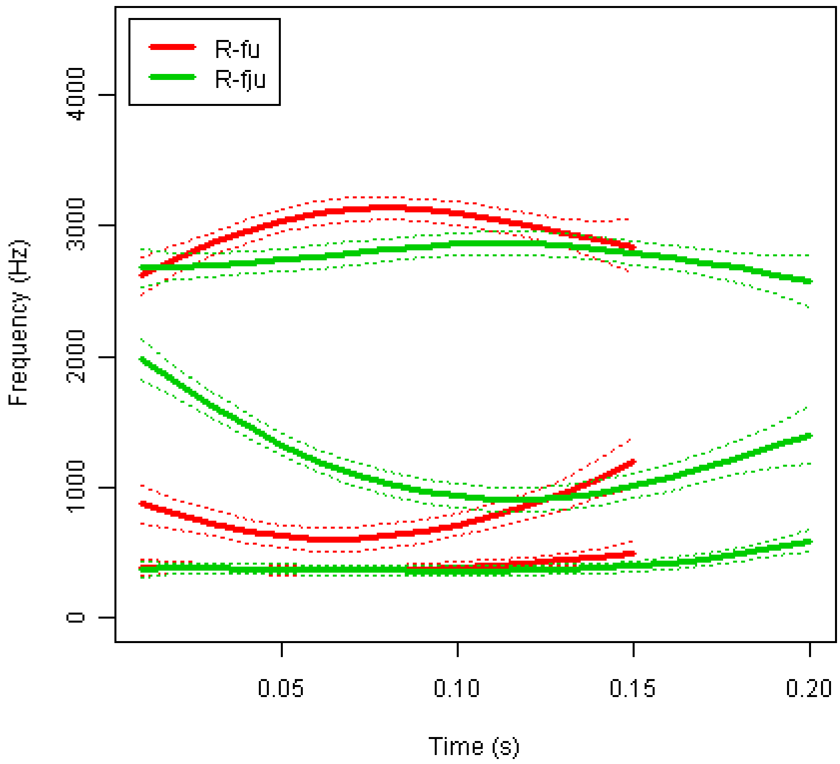


Figure 2.27d SSANOVA graph for [fu] & [fʲu], Russian

In summary, the major difference between the British [fju], on the one hand, and the Bulgarian and Russian [fʲu], on the other hand, is the presence of a steady state portion at the beginning of the F2 formant contour in the British SSANOVAs.

Next, we turn to the [su-sju] segmental sequences. As we can see from the SSANOVA graphs (Figures 2.28a-c) of the British subjects, they have lost the palatal glide in the word ‘super’. They no longer say [sju:per], but [su:per]. As the control word is [su:p], it is not surprising that the F2 contours overlap for all subjects. We also note that the F1 and F3 formant contours overlap with no significant difference, again for all subjects. Although we are unable to compare the British data to the other two languages, we include the graphs because they demonstrate that the Smoothing Spline Analysis of Variance (SSANOVA) (Gu, 2002) is a valid statistical technique for testing the difference(s) between segments.

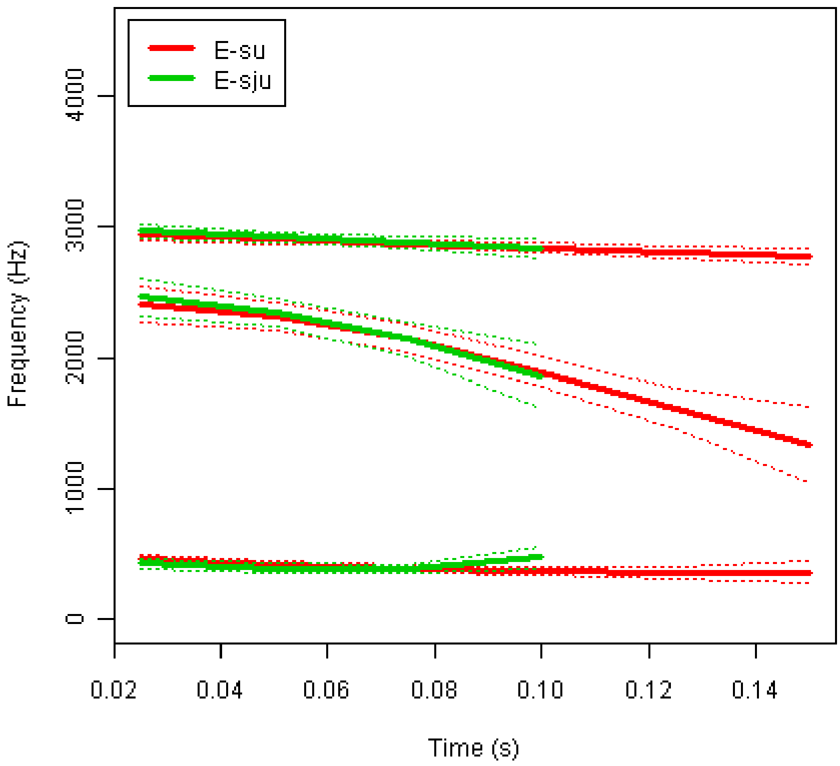


Figure 2.28a. SSANOVA graph for /su/ & /sju/, Subject E1, British English

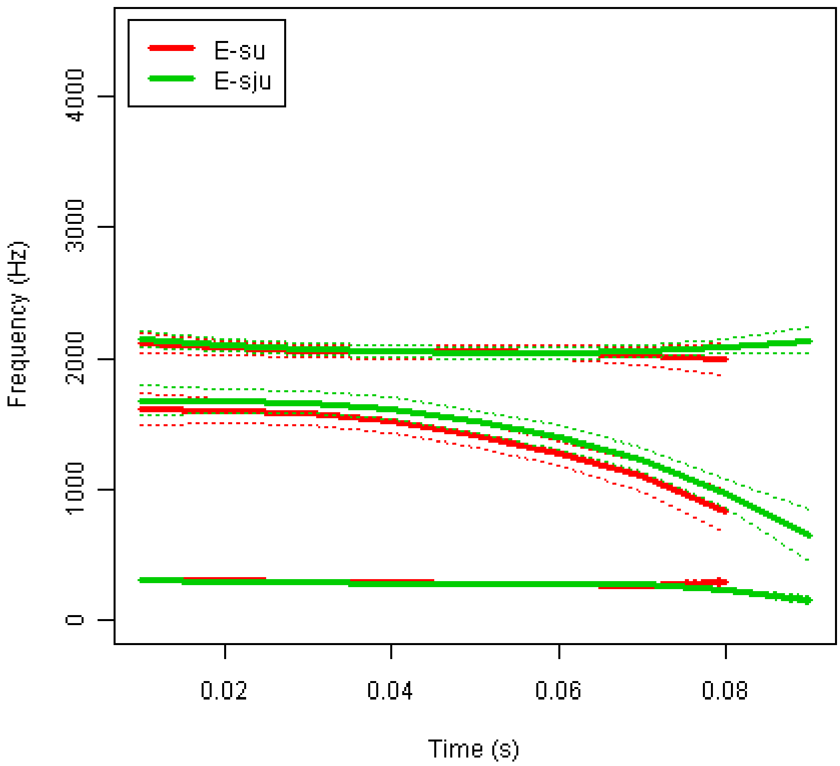


Figure 2.28b SSANOVA graph for [su] & [sju], Subject E3, British English

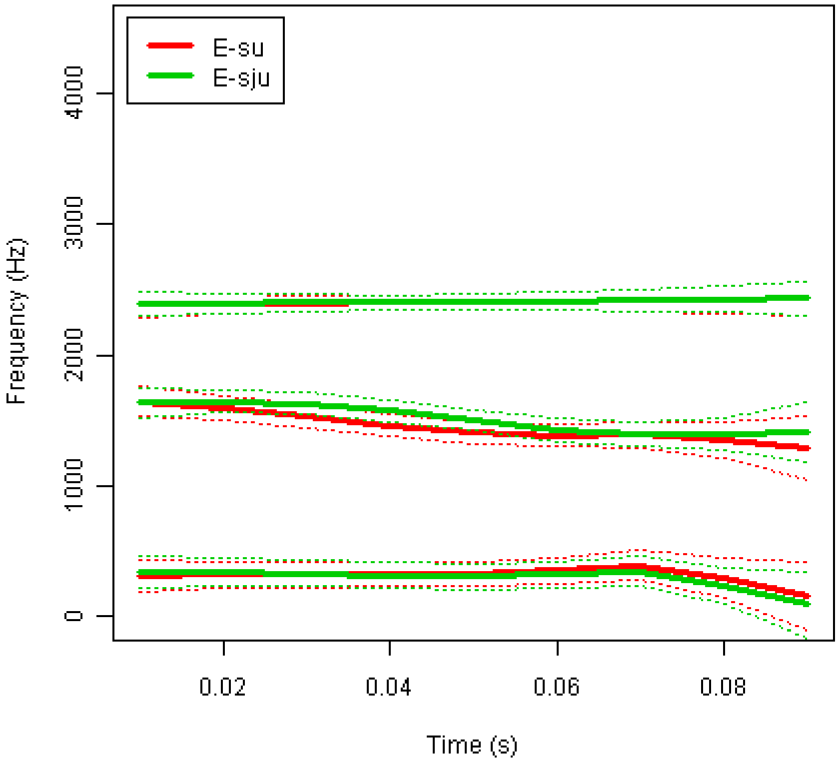


Figure 2.28c. SSANOVA graph for [su] & [sju], Subject E4, British English

The [su-s^{j}u] contrast is maintained by the Bulgarian and Russian subjects. The SSANOVA graphs are now shown here as they are identical to the [fu-f^{j}u] graphs. The confidence intervals of the [fu-f^{j}u] contrasts overlap at an average of 0.07 and 0.06 seconds for Bulgarian and Russian, respectively. Most individual averages range between 0.05 and 0.07 seconds for both languages, with medians of 0.06 and 0.065 seconds for Bulgarian and Russian, respectively, Figure 2.29.

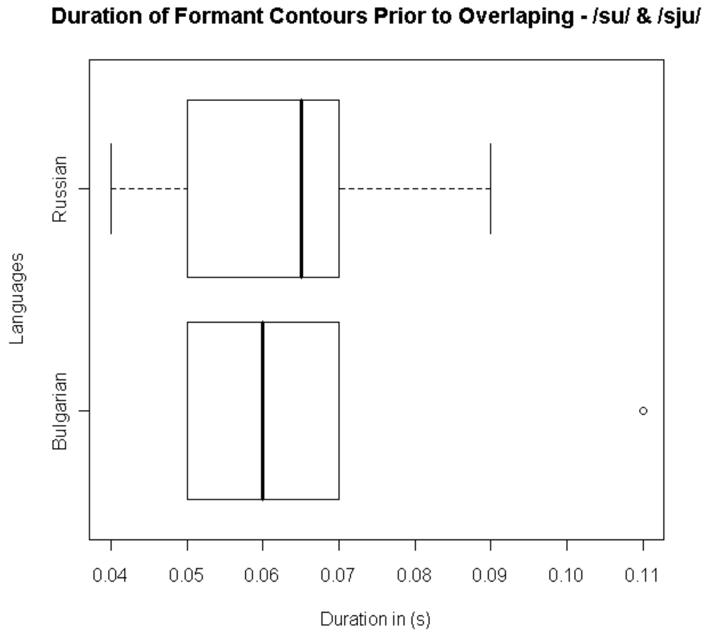


Figure 2.29 Boxplots of the duration of formant contours for the [sa-sʲa] contrast, prior to overlapping

In summary, in all three languages, the [fu-fju] contrast is preserved, according to the SSANOVA statistics. British English stands out with a steady state portion at the beginning of the F2 formant contour of [fju]. The British subjects have lost the palatal glide from 'super'. The [su-sʲu] contrast is preserved in Bulgarian and Russian. The [fa-fʲa] and [sa-sʲa] contrasts are preserved in Bulgarian and Russian, according to the Smoothing Spline ANOVAs of the Bulgarian and Russian data. We will not look at these graphs here because they convey information similar to the [fu-fju] graphs. Although the tongue is not involved in the formation of the primary articulation of [fʲ], the palatal glide was not measured for the Bulgarian and Russian data as the steady state was more difficult to delineate. The same applies to [vʲ].

With respect to the F2 formant contours of [vu] and [vju], there is a presence of a steady state portion along the F2 contour of [vju] as in the SSANOVA graph in Figure 2.30a, which is representative of the British data. It is reasonable to assume that this steady state portion can be related to the palatal glide. The transitions away from the palatal segment occur, on average, at 0.10 seconds for the British subjects. A steady state portion is not consistently apparent in the SSANOVAs of the Bulgarian and Russian subjects, as in Figures 2.30b and 2.30c. In some graphs one could see a steady state portion, as in 2.30d, Russian. We will come back to this issue in the discussion section.

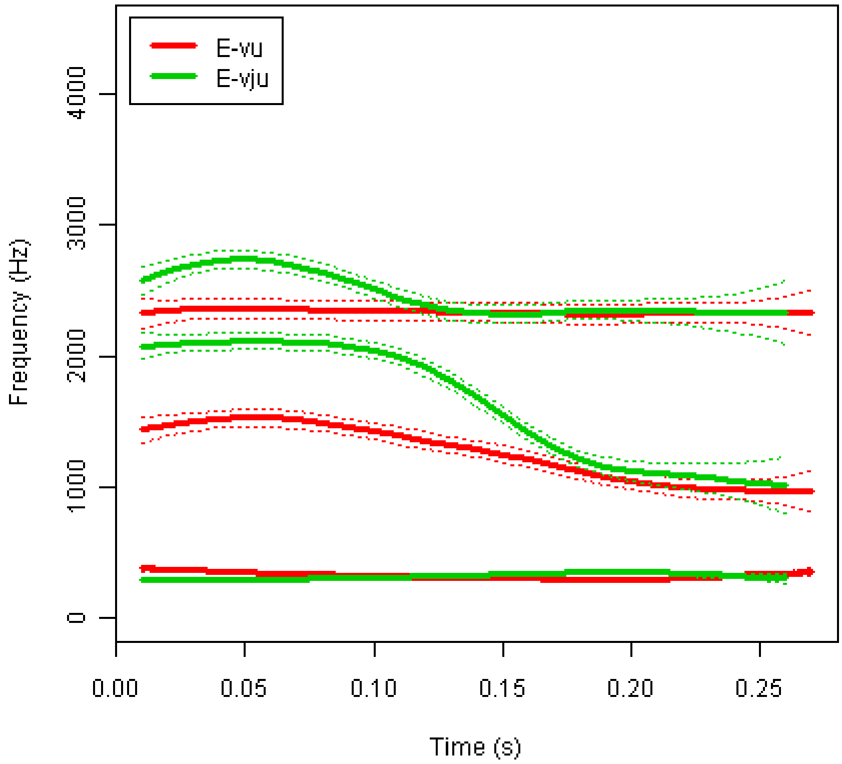


Figure 2.30a SSANOVA graph for [vu] & [vju], British English

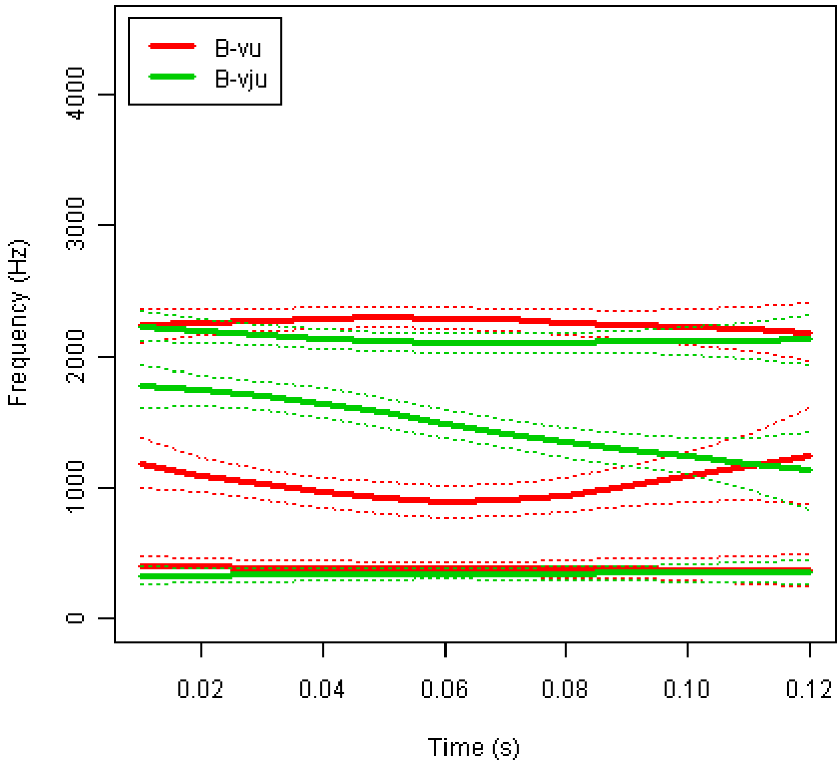


Figure 2.30b SSANOVA graph for [vu] & [vʲu], Bulgarian.

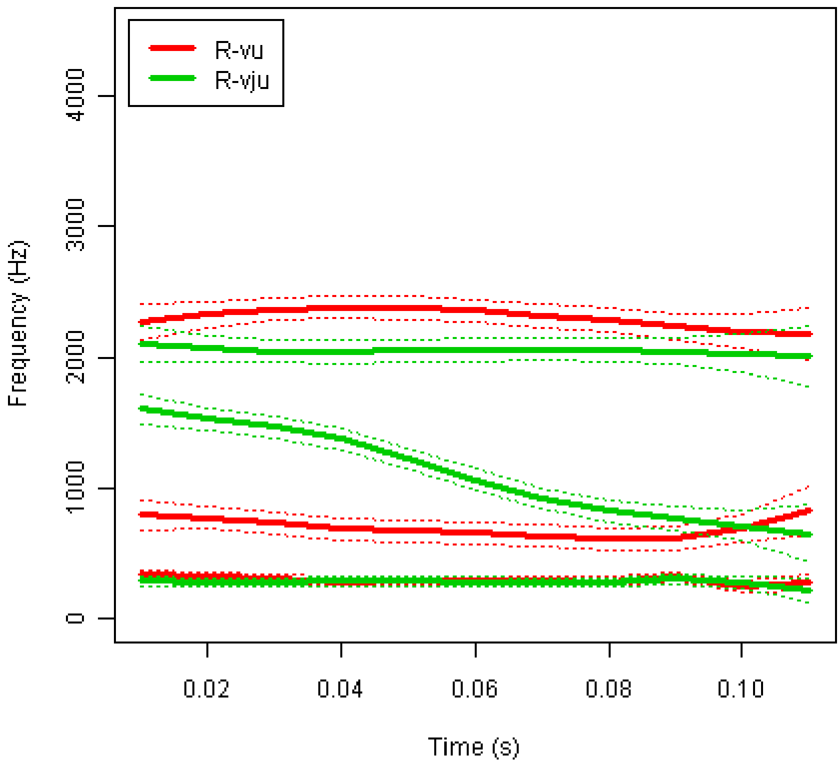


Figure 2.30c SSANOVA graph for [vu] & [vʲu], Russian.

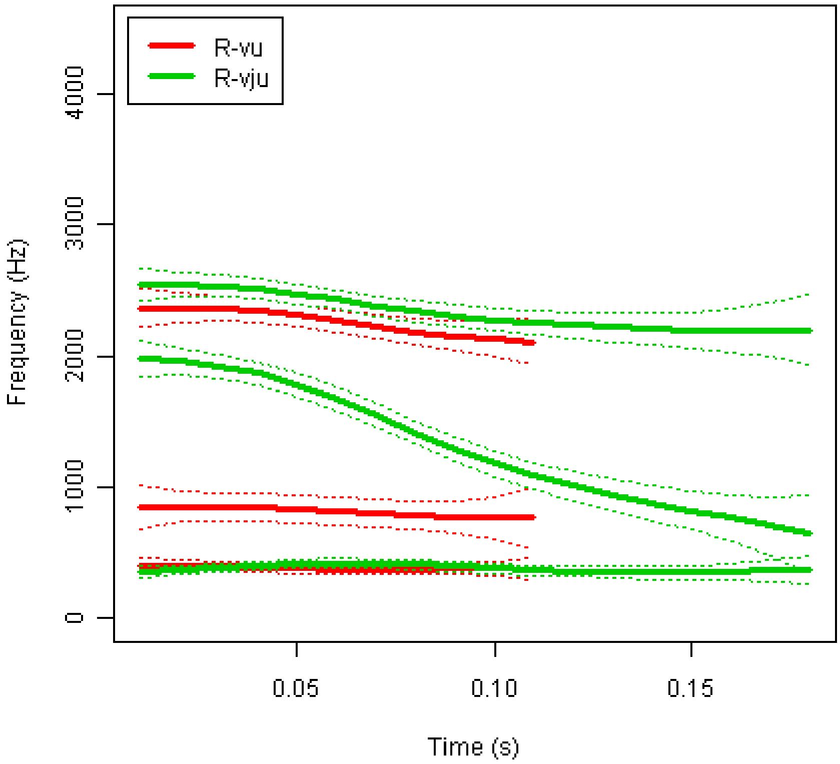


Figure 2.30d SSANOVA graph for [vu] & [vʲu], Russian

The boxplots in Figure 2.31 illustrate measurements of the time interval before the overlap of the F2 confidence intervals of [vu] and [vju], across languages. The majority of the British scores span between 0.20 and 0.024 seconds. However, even the lowest duration of 0.17 seconds is higher than the highest duration in Russian and Bulgarian, 0.12 seconds. The Bulgarian and Russian medians are 0.07 and 0.10 seconds, respectively.

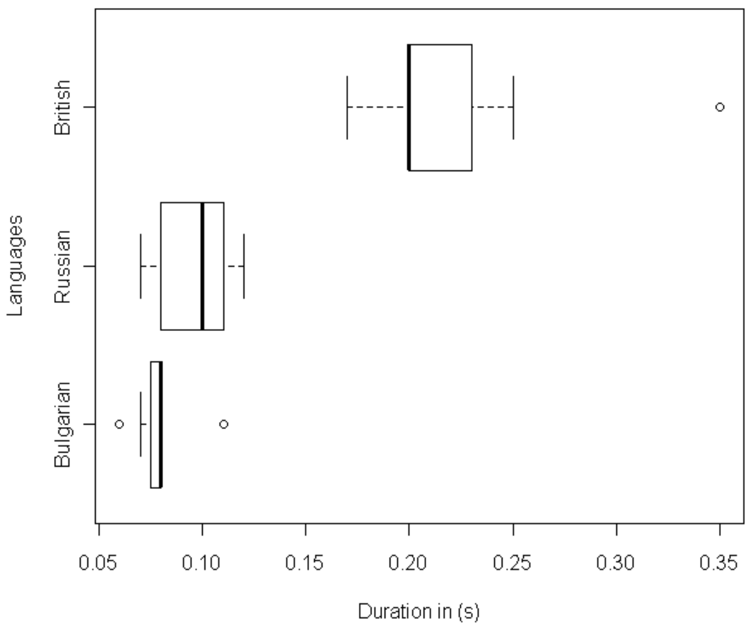


Figure 2.31 Boxplots of the duration of formant contours for the [vu-vju] contrast, prior to overlapping

The other voiced fricative contrast comparable across the three languages is [zu-zju]. The British English F2 contours from the SSANOVA graphs (Figure 2.32a, representative) are well separated, indicating the distinctness of the contrast. The formant contour begins with brief transition away from the consonant, followed by a steady state portion. The SSANOVA statistics indicate that the [zu-z^{j}u] contrast is maintained in Bulgrian and Russian (Figures2.32b and 2.32c, representative) as well. Apart from a few exceptions, one cannot identify a steady state glide portion. Furthermore, the overlap between the F2 confidence intervals of [zu] and [z^{j}u] occurs at 0.08 seconds, on average, for both language. The Bulgarian SSANOVA graphs look more like the Russian than the British ones.

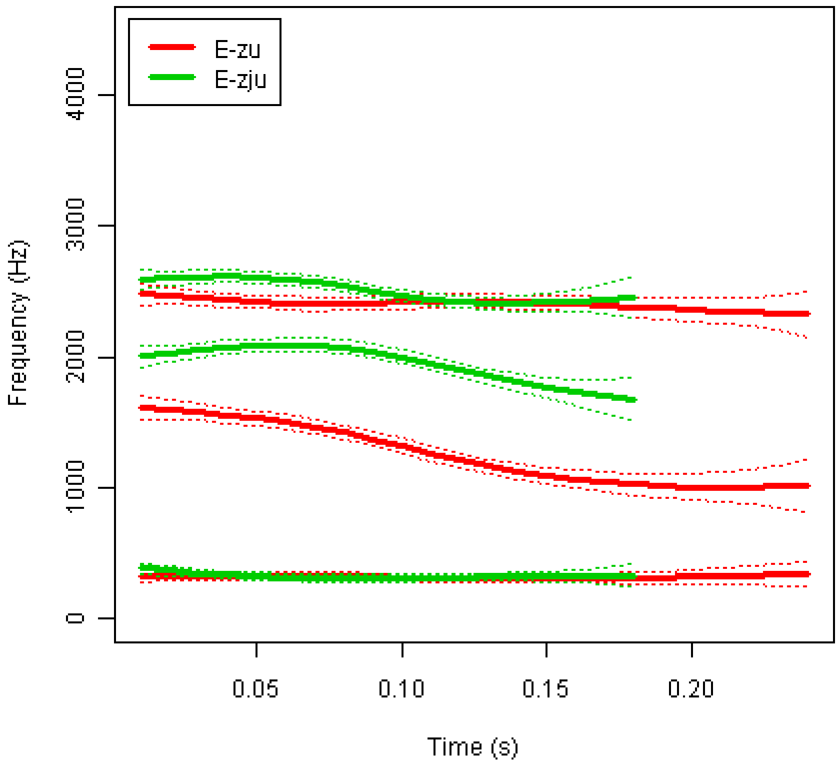


Figure 2.32a SSANOVA graph for [zu] & [zju], British English

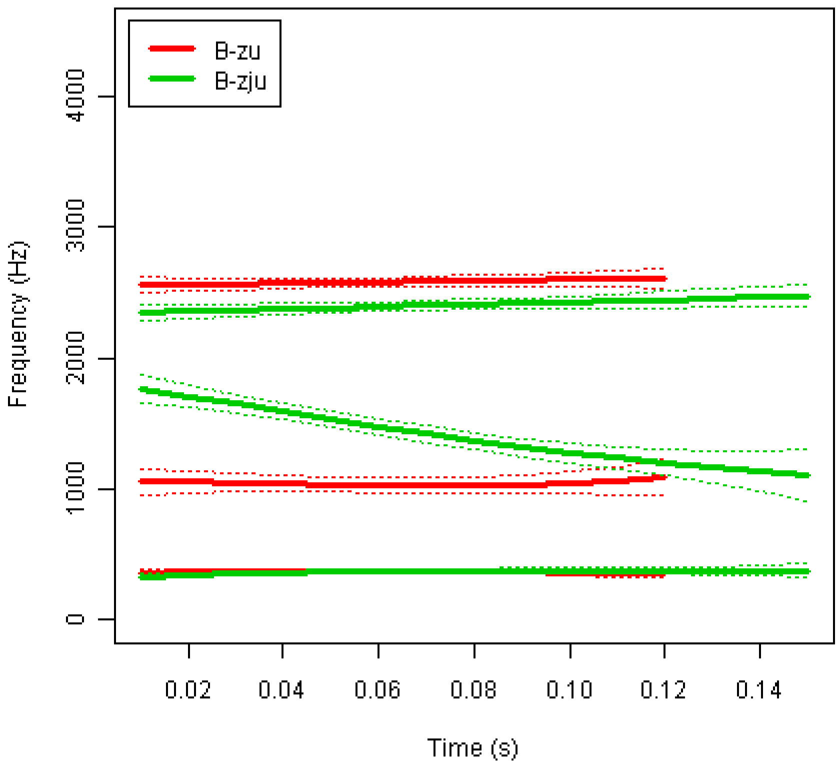


Figure 2.32b SSANOVA graph for [zu] & [zju], Bulgarian

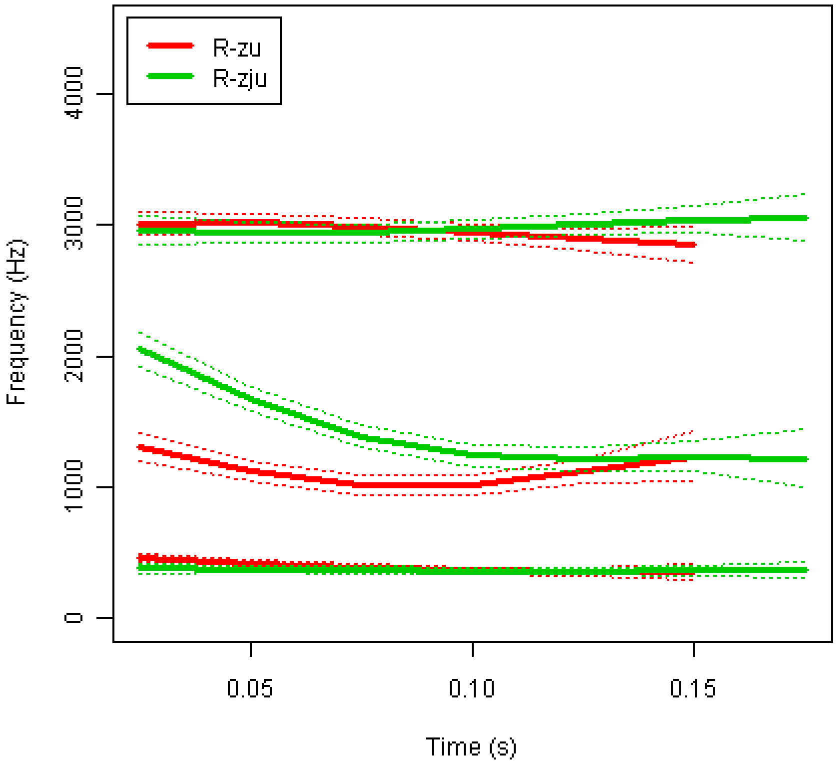


Figure 2.32c SSANOVA graph for [zu] & [zju], Russian

The [va-vʲa/ and [za-zʲa] contrasts are preserved both in Bulgarian and Russian. The SSANOVA graphs convey information very similar to that for the [vu-vʲu/ and [zu-zʲu] contrast. We will not go over them here to avoid repetition.

2.4.3 Plain and Palatalized Nasal Consonants Contrasts in the context of of the vowels [u] and [a]

We have successfully employed the Smoothing Spline ANOVA technique (Gu, 2002), so far, to establish if the [Cu-Cju] contrast exists in Bulgarian, Russian, and British English. The SSANOVA graphs and spectrograms have exhibited similarities, or differences, across languages. We have not yet addressed the issue as to whether the palatal segment is a primary or a secondary gesture. We will take this up in the discussion section.

Next we look at a representative SSANOVA [nu-nju] graphs of the British (Figure 2.33a), Bulgarian (Figure 2.33b) and Russian (Figure 2.33c) data. The F2 contours of the British [nju] sequence have the typical steady state portion and overlap, on average, at 0.15 seconds. The majority of the Bulgarian and Russian SSANOVA graphs lack even a brief steady portion. The F2 confidence intervals overlap, on average, at 0.07 seconds for both languages. Figure 2.34 displays boxplots of the durations of formant contours prior to overlapping, across languages.

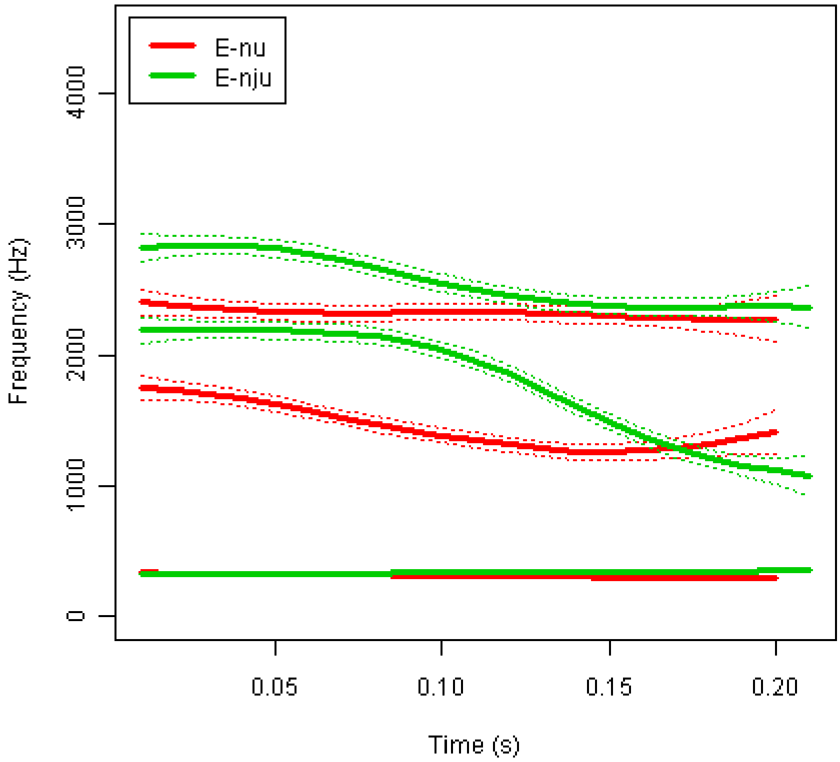


Figure 2.33a SSANOVA graph for /nu/ & /nju/, British English

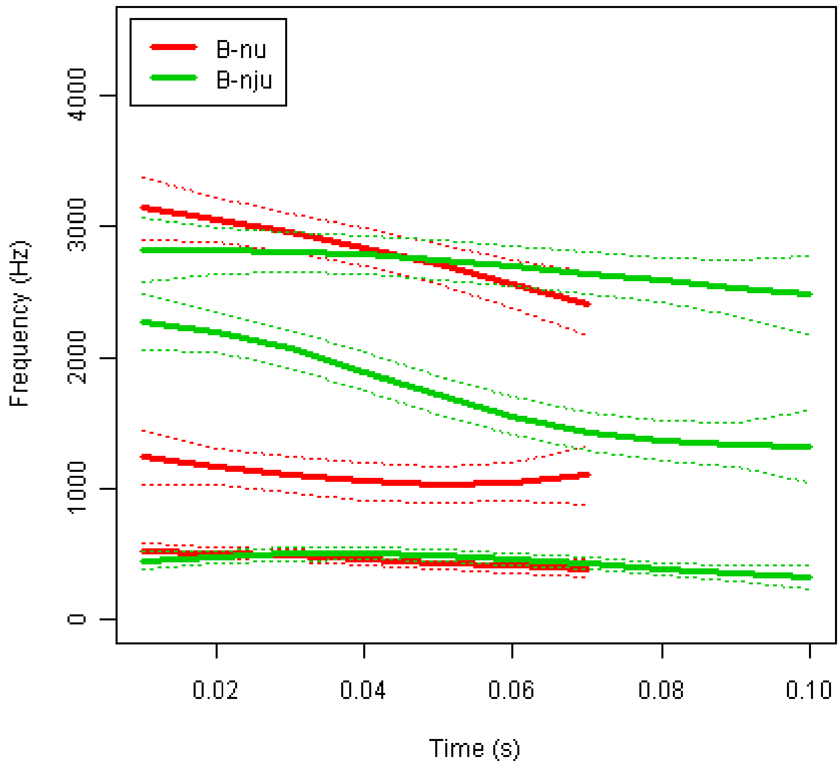


Figure 2.33b SSANOVA graph for /nu/ & /nʲu/, Bulgarian

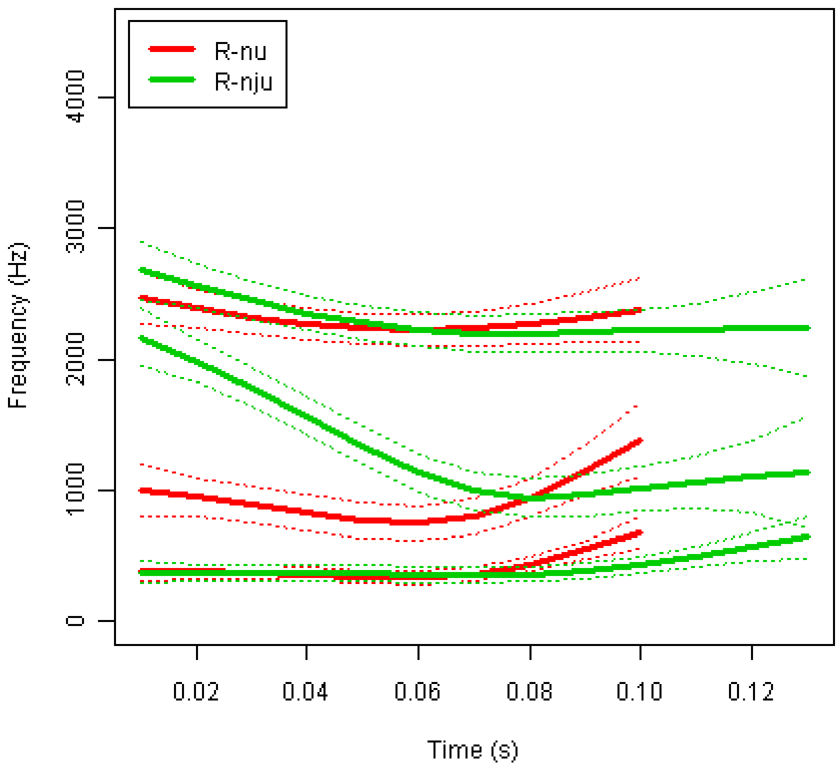


Figure 2.33c SSANOVA graph for /nu/ & /nʲu/, Russian

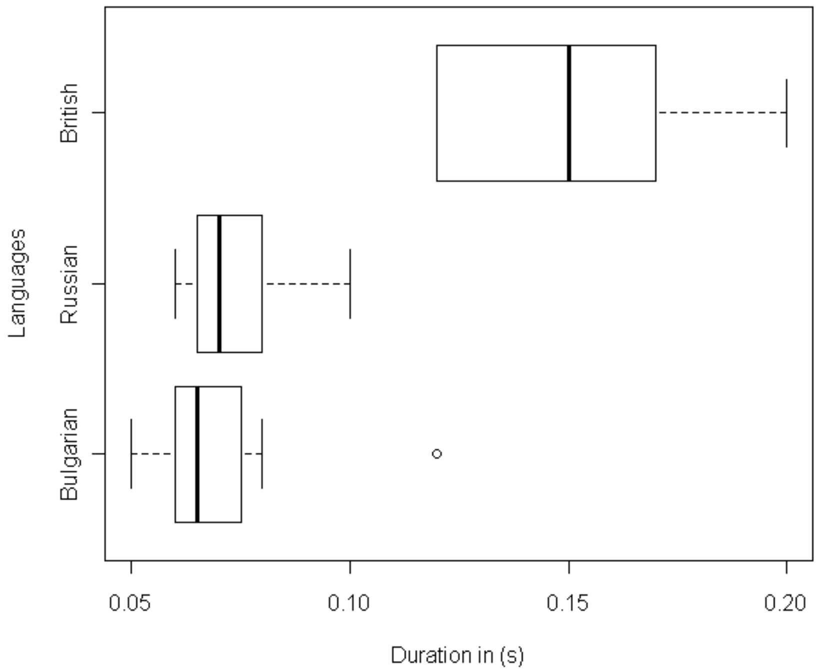


Figure 2.34 Boxplots of the duration of formant contours
for the [nu-nju] contrast, prior to overlapping

Recall that we were able to measure the duration of the glide in the case of the bilabial plosive consonants. This was possible as their place of articulation does not involve the tongue. Therefore, any formants post the release of these consonants could be associated with the glide (Ladefoged & Maddieson, 1996). We will now look at representative spectrograms of the British (Figure 2.35), Bulgarian (Figure 2.36), and Russian (Figure 2.37) subjects and compare the palatal glide across languages.

On a first inspection, we notice that, post the consonantal release, there is a longer steady state portion along the F2 formant in British English than in Russian and Bulgarian. The actual measurements of its duration confirm this. On average, the palatal glide measures as follows: 0.09 seconds for British English and 0.04 seconds for Bulgarian and Russian. Thus, in relation to Bulgarian and Russian, the duration measure of the palatal glide is identical between subjects, and between languages. British English stands out with the glide being just over twice longer in duration.

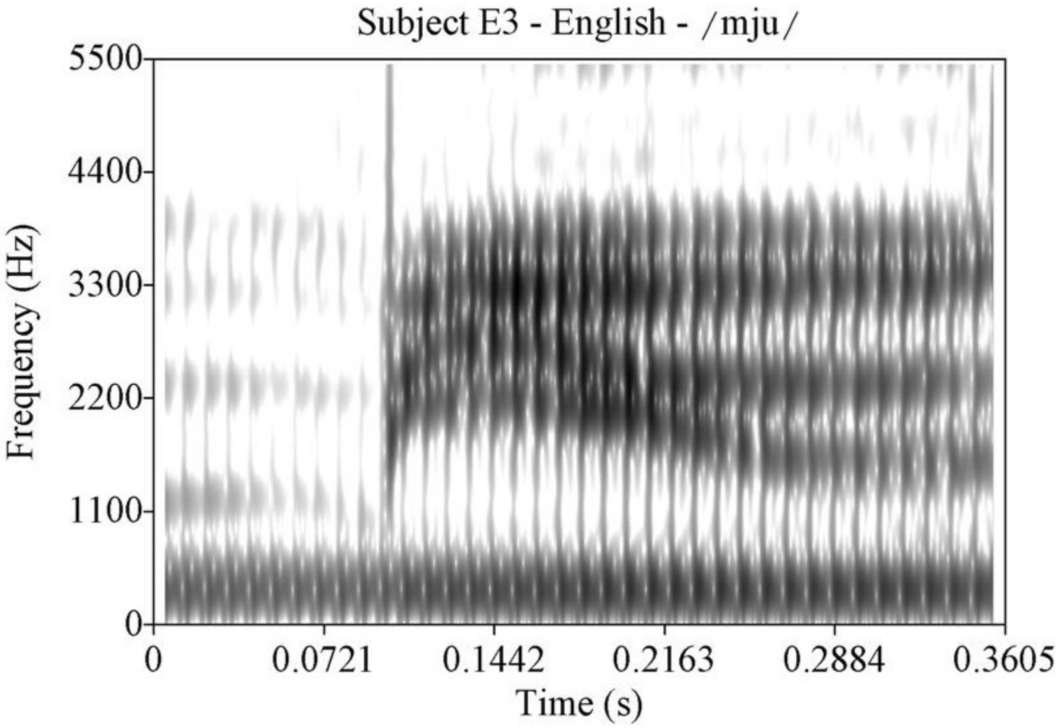


Figure 2.35 Spectrogram of [mju]; British English

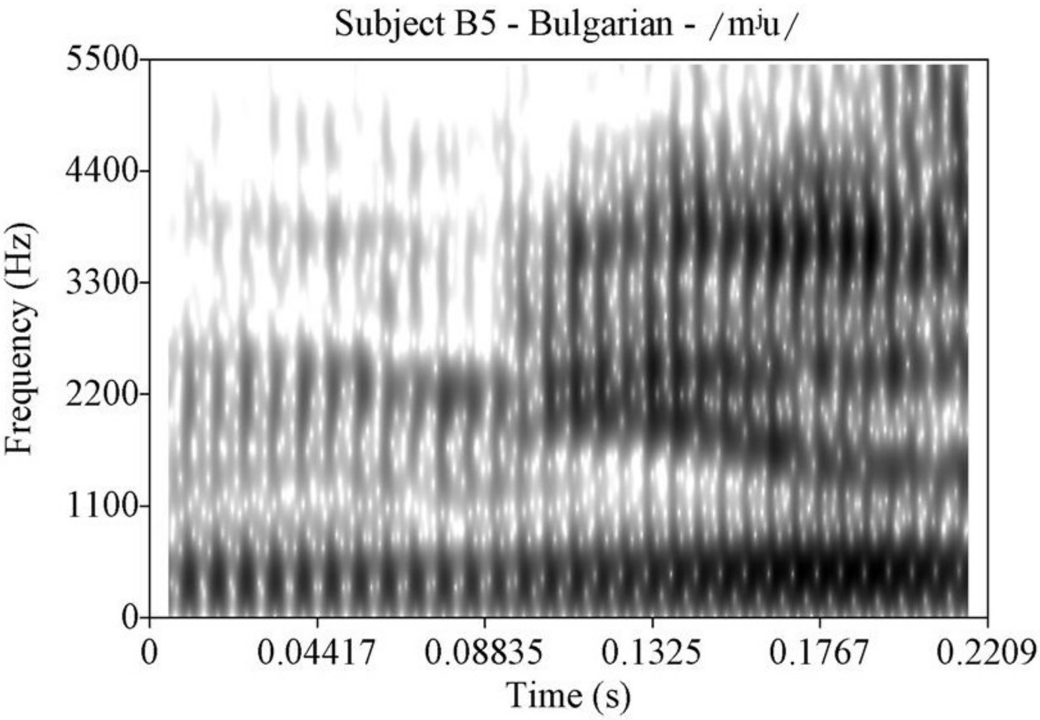


Figure 2.36 Spectrogram of [mʲu]; Bulgarian

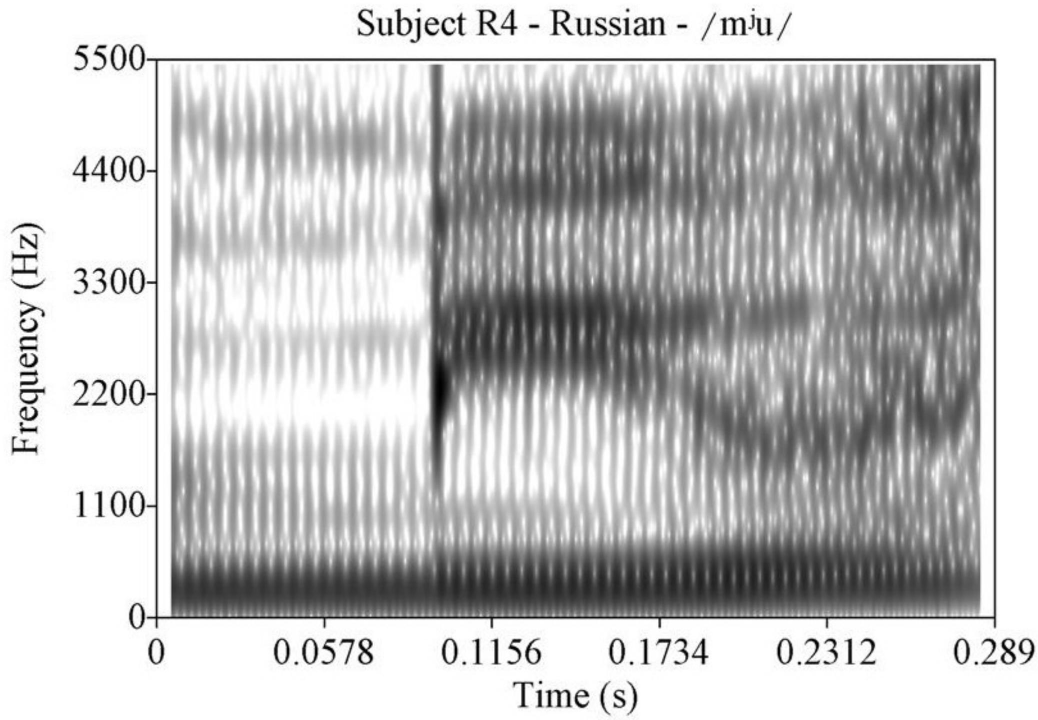


Figure 2.37 Spectrogram of [mʲu]; Russian

We also know that the [mu-mju] contrast is present in all three languages, as indicated by the representative SSANOVA graphs below, Figures 2.38a (British), 2.38b (Bulgarian) and 2.38c (Russian). Again, the steady state portion of the glide is not reflected in the graphs of most Russian and Bulgarian subjects, though it is obvious in those of the British subjects.

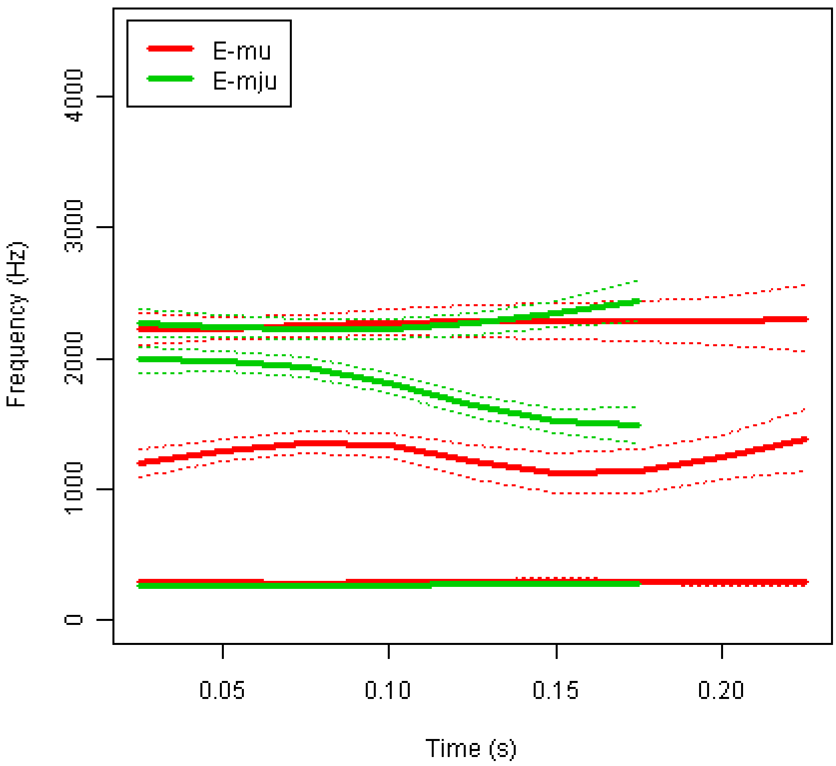


Figure 2.38a SSANOVA graph for [mu] & [mju], British English

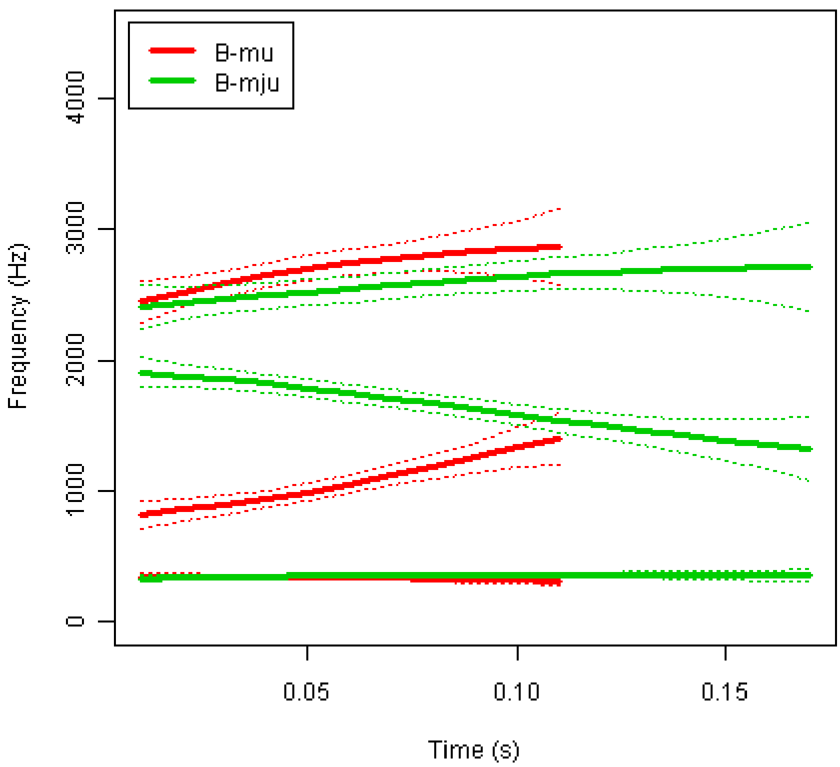


Figure 2.38b SSANOVA graph for [mu] & [m^{j}u], Bulgarian

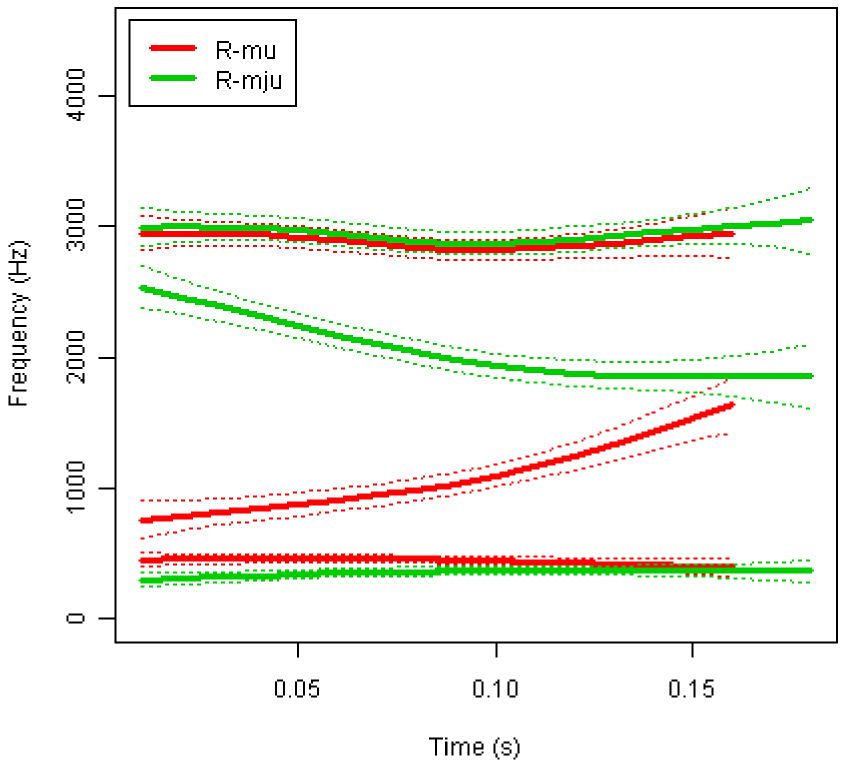


Figure 2.38c SSANOVA graph for [mu] & [mju], Russian

The [na-nʲa] and [ma-mʲa] contrasts are present in both Bulgarian and Russian. This is confirmed by the SSANOVA graphs of all subjects, across languages. The graphs look similar to the ones of the [nu-nʲu] and [mu-mʲu] contrasts. We will not discuss them here to avoid repetition.

2.4.4 Plain and Palatalized Lateral Approximant Contrasts in the context of the vowels [u] and [a]

The [lu-lju] contrast is preserved for five British subjects. The other three subjects have lost it. Following the transitions from [l], there is a steady state portion on the F2 [lju] contour in Figure 2.39a. The Bulgarian and Russian subjects have the [lu-l^ju] contrast as well, according to the representative SSANOVA graphs (Figures 3.39b and 2.39c). Their F2 [l^ju] formant contours slope down more sharply compared to the British ones. No steady state portions can be observed. Furthermore, the Bulgarian and Russian F2 confidence intervals overlap, on average, at 0.05 and 0.06 seconds, respectively. These figures contrast with the average time of overlap of 0.12s, on average, of the British F2 contours. The boxplots in Figure 2.40 illustrate the duration of formant contours for the [lu-lju] contrast prior to overlapping, across languages.

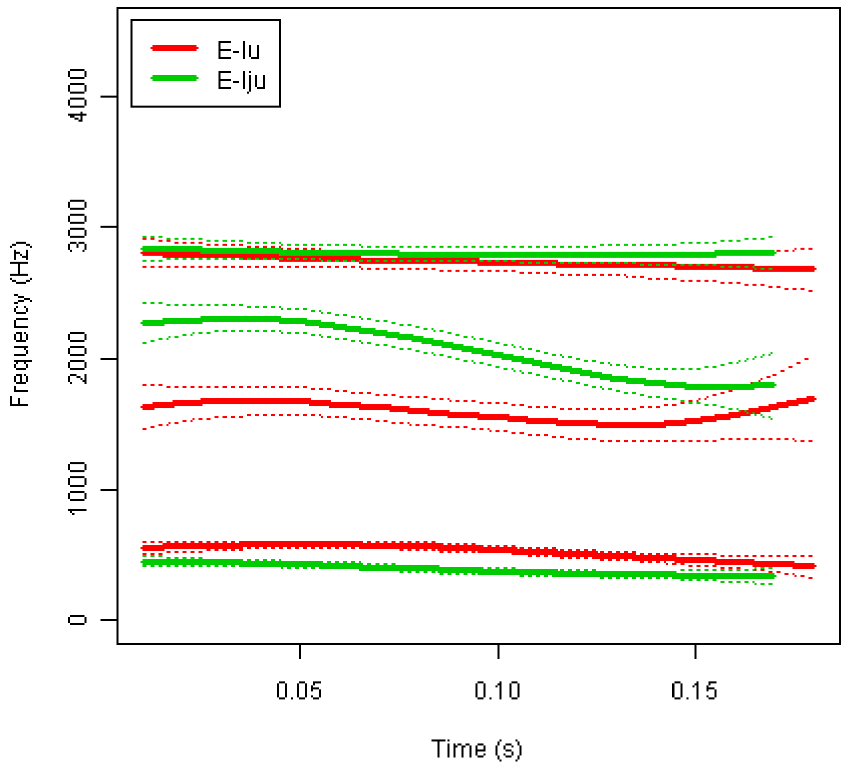


Figure 2.39a SSANOVA graph for [lu] & [lju], British English

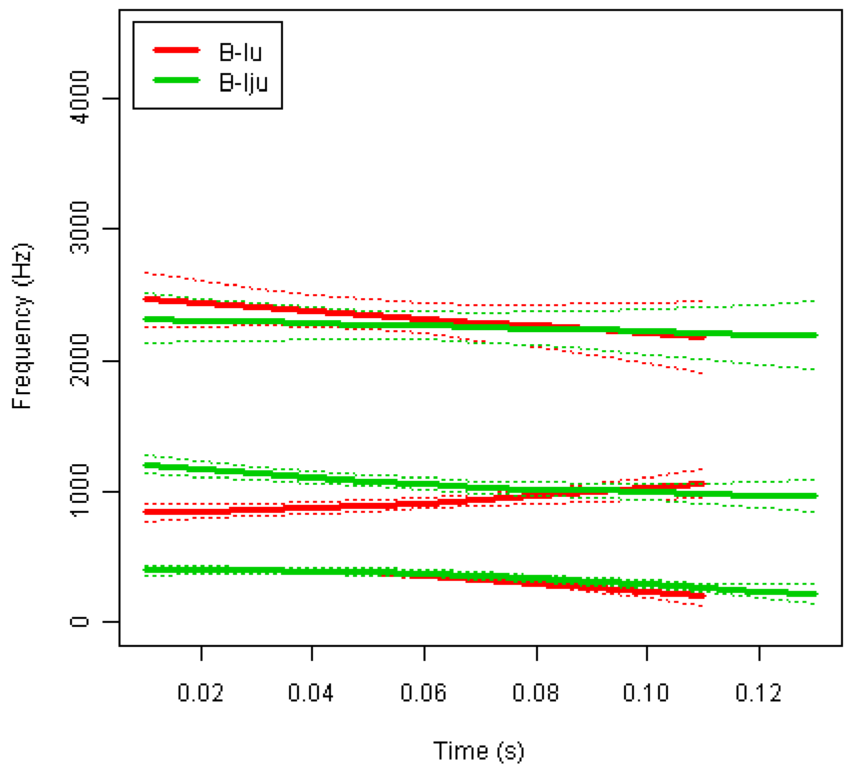


Figure 2.39b SSANOVA graph for [lu] & [lʲu], Bulgarian

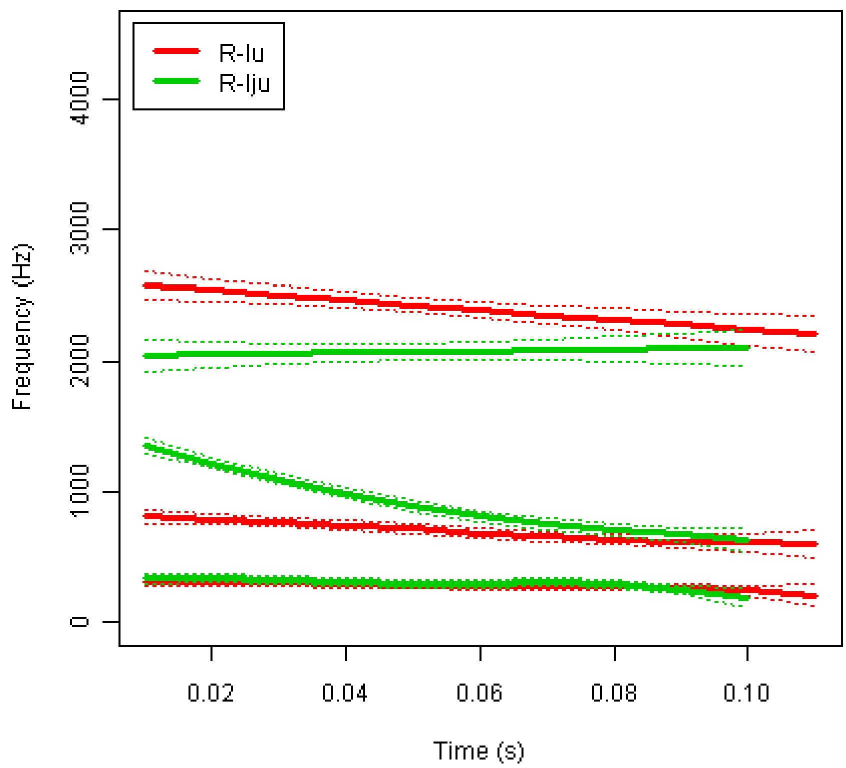


Figure 2.39c SSANOVA graph for [lu] & [lʲu], Russian

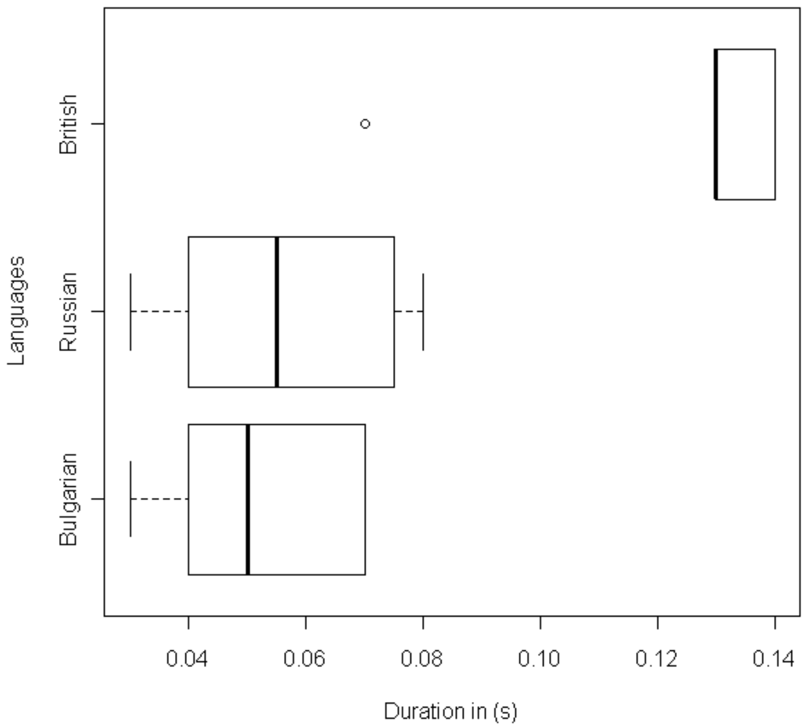


Figure 2.40 Boxplots of the duration of formant contours for the [lu-lju] contrast, prior to overlapping

The [la-lʲa] contrast is present in both Bulgarian and Russian, according to the SSANOVA graphs. The confidence intervals of the F2 contours overlap, on average, at 0.12 and 0.13 seconds for Bulgarian and Russian, respectively. The graphs are identical to those of the [lu-lʲu] contrast, thus, they are not displayed here. As it was the case of the other contrasts, the F2 [la-lʲa] formant contours are mostly informative of the existence of the contrast. They do not give any information as to whether the glide is a primary or a secondary gesture.

2.4.5 Plain and Palatalized Alveolar Trill Contrasts in the context of the vowels [u] and [a]

The [ru-rʲu] contrast is maintained in Bulgarian and Russian, as confirmed by the representative SSANOVA graphs, Figures 2.41a and 2.41b, respectively. The F2 formant contours of [ru] and [rʲu] overlap, on average, at 0.07 and 0.08 seconds for Bulgarian and Russian, respectively. The boxplots in Figure 2.42 display the range of scores of the duration of the [ru-rʲu] contrast prior to overlapping, across languages.

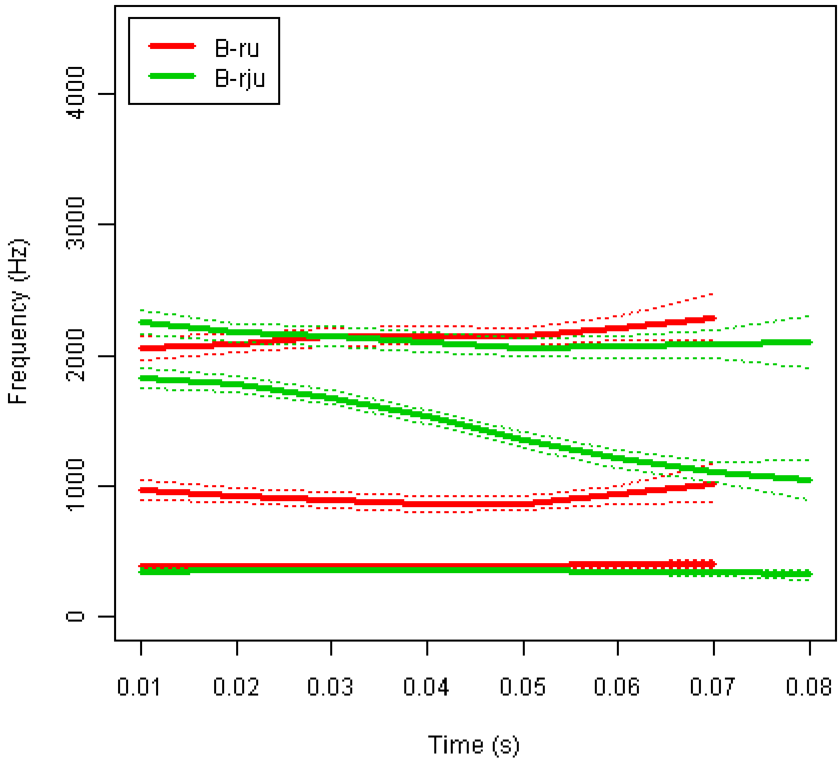


Figure 2.41a SSANOVA graph for [ru] & [rʲu], Bulgarian

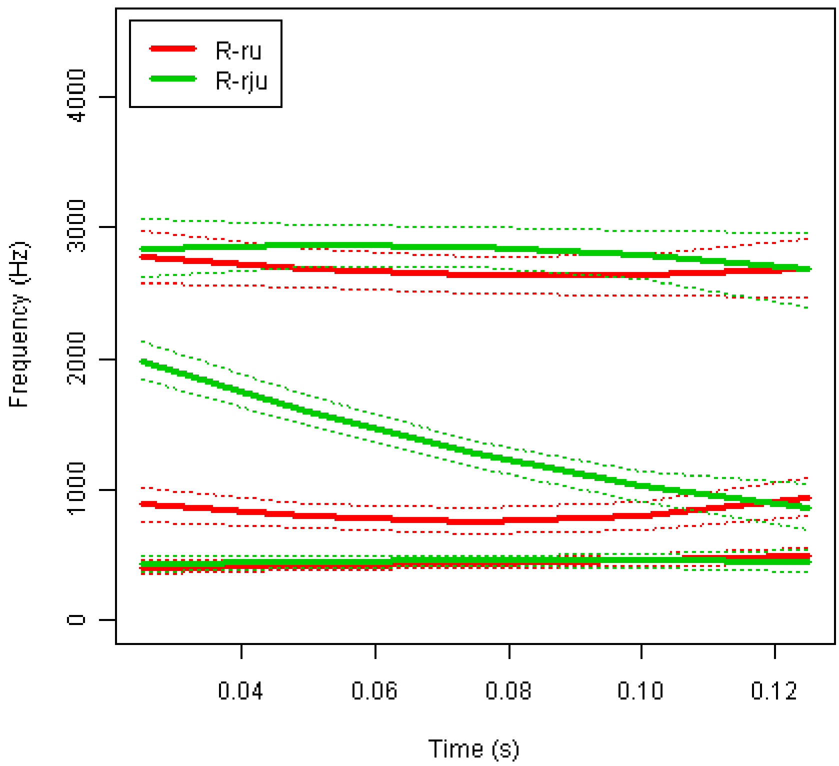


Figure 2.41b SSANOVA graph for [ru] & [rʲu], Russian

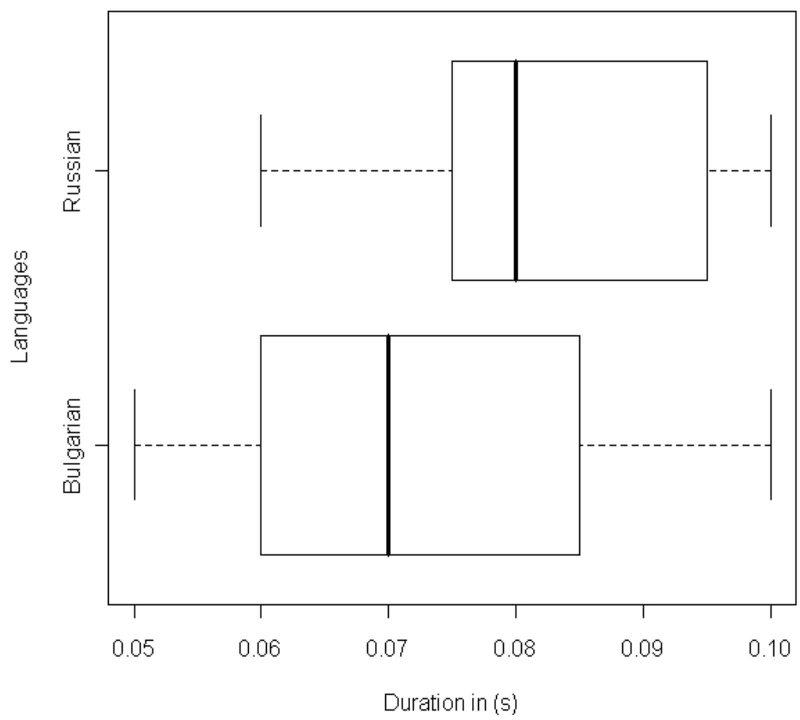


Figure 2.42 Boxplots of the duration of formant contours for the [ru-rʲu] contrast, prior to overlapping

The SSANOVA graphs of [ra-r^{j}a] indicate that the contrast is maintained in both Bulgarian and Russian. As the information conveyed by the graphs is similar to that of the [ru-r^{j}u] graphs, we will not display them here. The contrast is maintained for a duration of 0.08 and 0.11seconds for Bulgarian and Russian, respectively. It is unclear as to why the duration is slightly higher for the Russian subjects. This variation is also reflected in the boxplots in Figure 3.43, which illustrate the time elapsed prior to the overlap of the confidence intervals of the [ra-r^{j}a] contrasts.

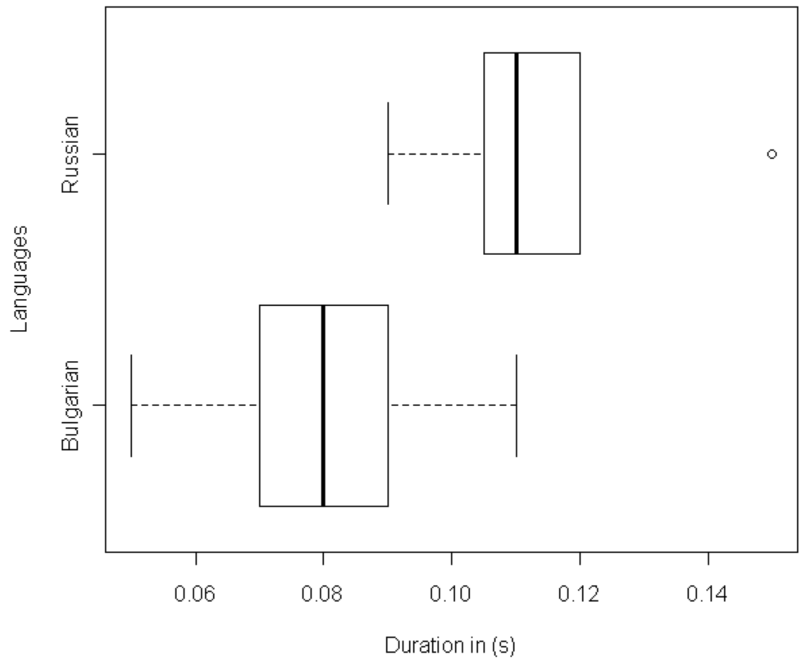


Figure 2.43 Boxplots of the duration of formant contours for the [ra-r^{j}a] contrast, prior to overlapping

2.5 Discussion

The goal of this acoustic study was to investigate if the palatalized consonants of Standard Bulgarian have undergone depalatalization, which was defined as the decomposition of a secondary palatal [ʲ] gesture into a palatal glide [j]. The acoustic data (F1, F2 and F3 frequencies) was analyzed with a Smoothing Spline ANOVA, a statistical technique which, in the case of this study, shows if two curves, or formant contours, are the same or different. The F2 contours are of a particular interest as palatalization is associated with the raising of F2 frequencies. All possible segmental environments ([Cju] and [Cja]) listed in Table 2.1, page 10, were included in the SSANOVA analyses. The results were compared among all three languages of investigation in the context of the vowel /u/, and between Bulgarian and Russian in the context of the vowel [a].

With regards to the plosive consonants, the regression lines associated with the F2 values of the plain and palatalized sequences indicate that the contrast is maintained in all three languages. The lines are well separated, until the point of overlap of the confidence intervals, which also means that the difference is statistically significant. For some subjects, in all three languages, the F2 formant contours remained apart for the entire duration of the plain and palatalized sequences. In those cases, we made the inference that, due to coarticulatory processes, palatalization raised the F2 formant frequencies of the vowel, [u] or [a], over the entire spectrum.

Although the SSANOVA graphs confirmed the existence of 'plain' and 'palatal' contrasts, it was unclear as to whether the palatal segment was a primary [j] gesture or a secondary [ʲ] gesture. Therefore, we referred to the spectrograms of the palatal sequences ([Cju] and [Cja]) of the bilabial consonants [p] and [b]. According to Ladefoged and

Maddieson (1996), the formants found after the release of these consonants can be associated with the palatal glide, be it a secondary or a primary gesture, as the tongue does not participate in the formation of the place of articulation of the bilabial consonants Moreover, these researchers state that, acoustically, the main difference between a primary and a secondary palatal glide gesture consists of the presence, or lack, of a steady state portion of the formant contours. Thus, this criterion was used in the inspection of the relevant spectrograms. (As we mentioned earlier, labialization lowers the F2 vowel formants. However, this will occur in the environment of both the plain and palatalized labial consonants. As we are controlling the segmental environments, labialization is not expected to be a confound in neither dependent measures, the contrast duration and the duration of the palatal element.)

Ladefoged and Maddieson's (1996) criterion is descriptive in nature. It also turned out to be ambiguous in relation to the Bulgarian and Russian /p^j/ spectra. While it is true that on some of the spectrograms (e.g., Figure 2.9a, p. 22; Figure 2.10, p. 24) a steep transition slope begins from the release of the consonant towards the following vowel, on other spectrograms (Figure 2.9b, p. 23), there is a clearly identifiable 'steady state' portion. We introduced a quantifiable measure of the palatal segment, the duration in seconds, of the steady state element. The average measurements of the palatal glide indicated that is 0.02 seconds in Russian and 0.03 seconds in Bulgarian. This is in contrast with the duration of the palatal glide in British English, 0.05 seconds, on average. Thus, in terms of the durational measure, the Bulgarian glide is more like the Russian than the British glide. In addition, Bulgarian is comparable to Russian in terms of the elapsed time, 0.10 seconds on average, before the F2 confidence intervals of the plain and palatal sequences overlap. British English maintains the difference for a period of 0.017 seconds, on average, which probably reflects the longer VOT and glide duration.

The average duration of the Bulgarian and Russian steady state palatal glide portion in the [b_u] context is 0.04 seconds. In the same context, the duration of the British glide is longer, with an average of 0.08 seconds. In terms of the SSANOVA F2 formant contours, the difference between the plain and palatal sequences is maintained for an average period of 0.10 seconds in Bulgarian and Russian, and 0.14 seconds in British English. Thus, in the environment of the bilabial plosive consonants and the vowel [u], the Bulgarian palatal glide is identical to the Russian glide, based on the data from the duration of the steady state portion. With respect to the F2 formant contours in the SSANOVA graphs, both languages maintain the difference between the plain and palatal sequence for an average of 0.10 seconds. So far, on the grounds of the acoustic information and SSANOVA statistics, it appears that the Bulgarian palatalized [p^j] and [b^j] have not undergone depalatalization.

The duration of the palatal segment of the palatalized bilabial plosive consonants in the context of the vowel /a/ is the same for Bulgarian and Russian. It is 0.03 and 0.04 seconds for [p^j] and [b^j], respectively. These measures strengthen the evidence that the palatal segment is a secondary gesture. In terms of the SSANOVA graphs, the Bulgarian and Russian [pa-p^ja] and [ba-b^ja] differ in an interesting way. The Russian F2 contours remain apart throughout the entire duration. Palatalization raises the F2 frequency of the vowel in the palatal sequence to an extent that the confidence intervals of the plain and palatalized vowel remain apart for all subjects in the case of [pa-p^ja], and the majority of subjects in the case of [ba-b^ja]. In Bulgarian, the F2 contours overlap around 0.12 seconds for [pa-p^ja] and 0.13 seconds for [ba-b^ja].

The raising of F2 is associated with the narrowing of the frontal cavity and a high tongue position as for high front vowels. Also, front vowels tend to have higher F2 compared to back vowels. Usually, the vowel [a] has lower F2 formant frequency, as it is articulated further back in the mouth. Although this is not an articulatory study, if we refer to articulatory-acoustic correlates, we may hypothesize that the Russian /a/ is higher in the palatal context due to the higher tongue position of the palatal glide as a secondary gesture. However, when we look at other palatalized consonant environments (e.g., [dʲa]), the Russian F2 confidence intervals overlap in a similar way as the Bulgarian ones. It is impossible to tell if the Russian secondary palatal gesture is articulated with a higher position of the back of the tongue.

The plain-palatal contrast is clearly maintained for the remaining plosive consonants (t – tʲ/tj; d – dʲ/dj; k – kʲ/kj; g – gʲ/gj) in the environment of [u] for all languages of investigation. This is confirmed by the SSANOVA statistics which show that the F2 formant contours are distinct, at least up to the point where the confidence intervals overlap. The boxplots in Figure 2.44 illustrates that the British contrast of the voiceless plosives remains distinct for a longer duration. The longer VOT of the British voiceless consonants would undoubtedly contribute to the longer duration. However, by analogy to the British [bju] sequence, it is reasonable to assume that the length of the duration is also influenced by the palatal glide. This is certainly confirmed by the boxplots of the voiced plosive consonants in Figure 2.45 where aspiration is not an issue. The plain-palatal contrast is also maintained in the environment of the vowel [a] for Bulgarian and Russian voiceless (Figure 2.46) and voiced (Figure 2.47) plosive consonants.

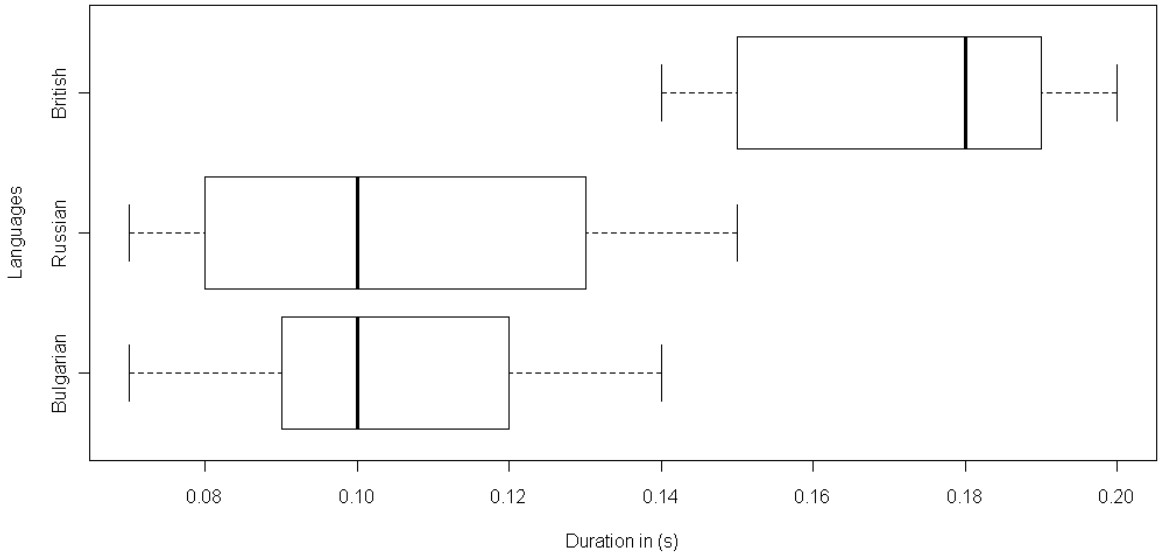


Figure 2.44 Cross-language comparison of the duration of F2 formant contours of voiceless plosive consonants prior to overlapping, in the context of [u]

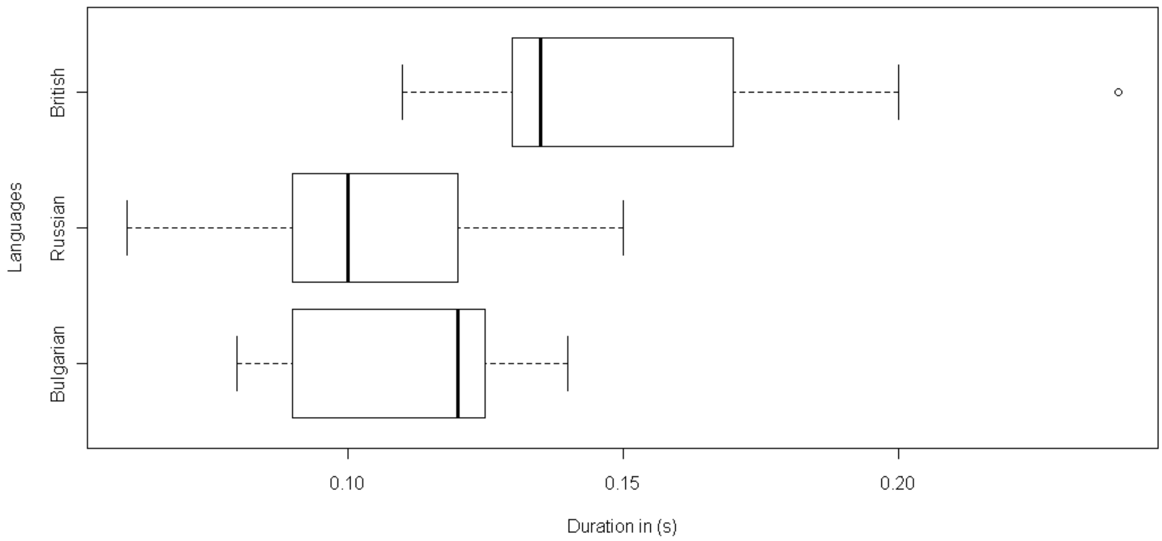


Figure 2.45 Cross-language comparison of the duration of F2 formant contours of voiced plosive consonants prior to overlapping, in the context of [u]

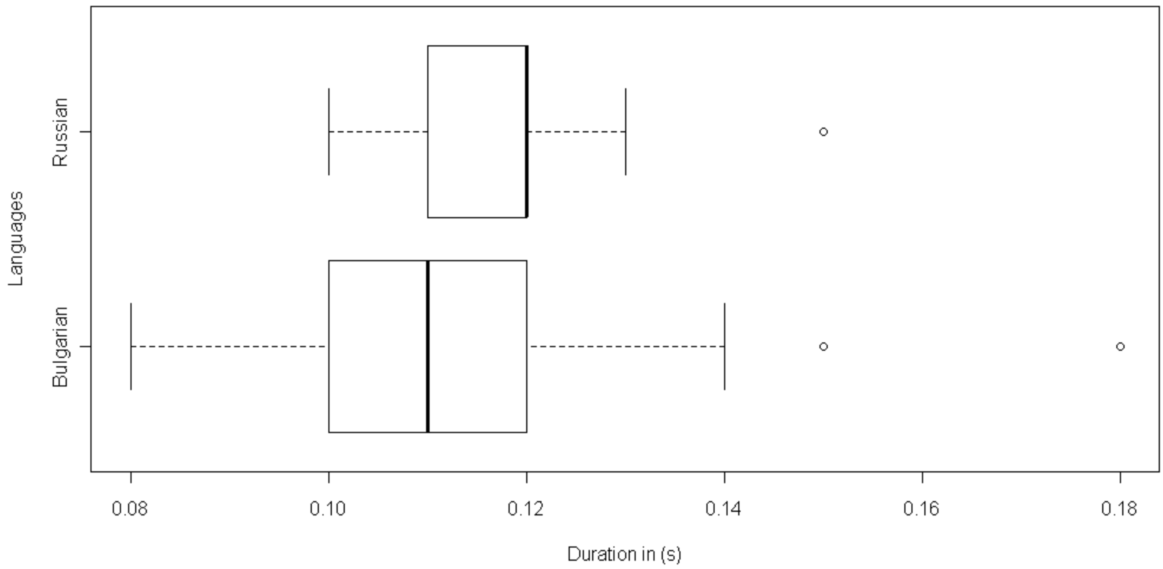


Figure 2.46 Cross-language comparison of the duration of F2 formant contours of voiceless plosive consonants prior to overlapping, in the context of [a]

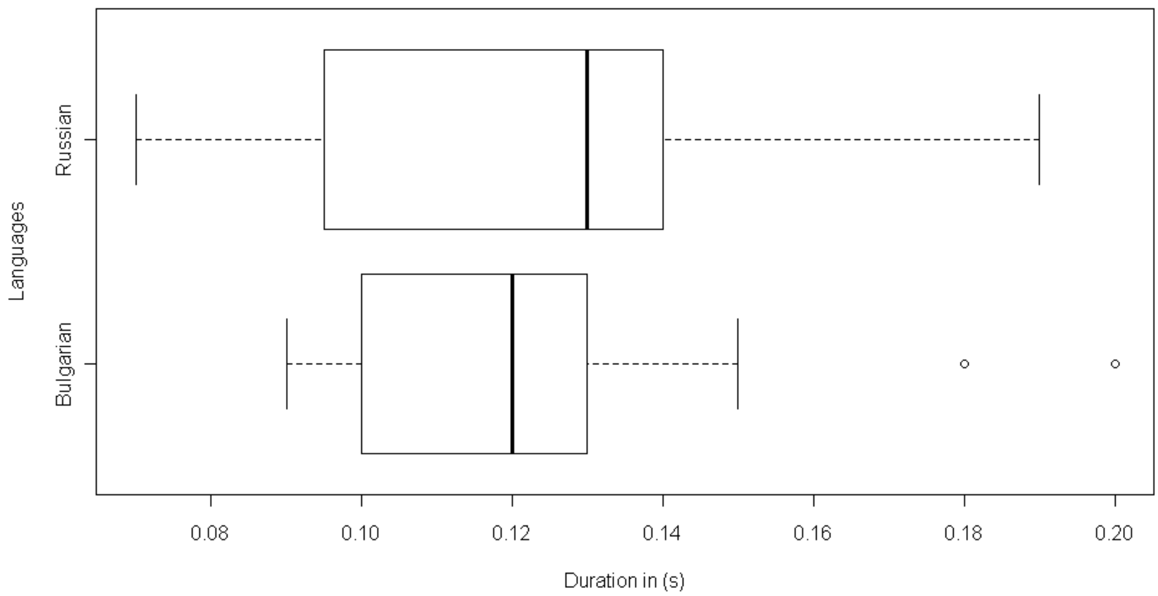


Figure 2.47 Cross-language comparison of the duration of F2 formant contours of voiced plosive consonants prior to overlapping, in the context of [a]

Thus, according to the SSANOVA F2 formant contours, the plain and palatal contrast of plosive consonants is maintained for a similar duration in Bulgarian and Russian. For both languages, the average figure for the voiceless plosives is 0.10s in the environment of the vowel [u], and 0.12 seconds in the environment of the vowel [a]. The plain-palatal contrast of voiced plosives is maintained for an average of 0.11 seconds in the context of the vowel [u], for both languages, and for an average of 0.12 and 0.13 seconds for Bulgarian and Russian, respectively, in the context of the vowel [a]. British English stands out with an average of 0.17 and 0.15 seconds for the voiceless and voiced plosives, respectively.

The duration of the palatal glide was not measured for plosive consonants other than [p] and /b/ as the tongue is involved in the articulation of the primary and secondary gesture. So, can the F2 contours in the SSANOVA graphs inform us of the duration of the palatal segment? Recall that, in the results section, we mentioned that the steady state glide portion is not obvious on all Smoothing Spline ANOVA graphs. Recall also that smoothing splines have a smoothing parameter which attempts to find the best fit for variable data. Although we control the speed of articulation of stimuli through the stimulus speed of presentation, there is still the possibility for some variation. This is in a way desirable because it contributes to the naturalness of the acquired speech data. Thus, we have some variability in the duration of the recorded tokens. There are seven tokens for each stimulus. The drawings in Figure 2.48 represent an attempt to show what an individual F2 formant contour of a single stimulus would look like, as well as a bunch of F2 contours of the same stimulus. The smoothing parameter consists of a function that attempts to fit the data, and of another one that penalizes a fit without an appropriate amount of smoothness (Davidson, 2006). The interaction of the two functions can produce a straight line, instead of a 'curly' approximation of a curve, as a best fit of the data.

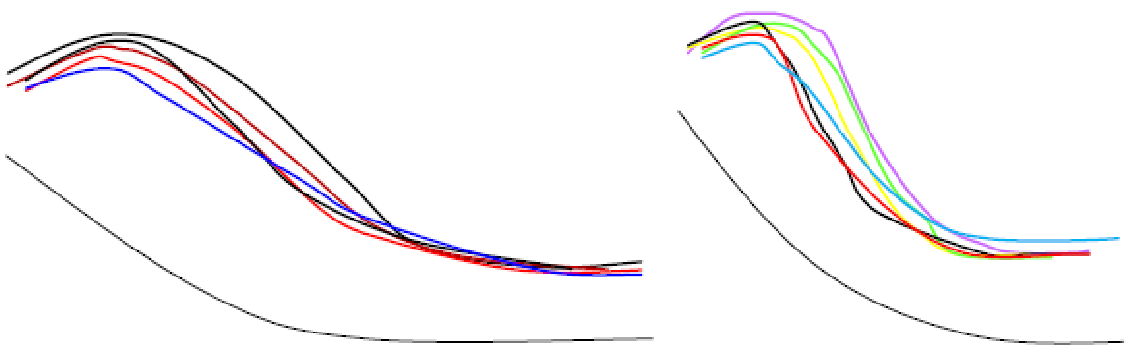


Figure 2.48 Demonstration of the Smoothing Parameter

Irrespective of this 'smoothing issue', the F2 contours of some of the subjects reflect the steady state glide portion. Therefore, it is reasonable to assume that: (1) by controlling the speed of presentation, we were largely able to acquire natural data, of similar duration across tokens of the same stimulus; (2) the Smoothing Spline ANOVA is successful in representing the data faithfully.

We rely exclusively on the SSANOVA graphs to find out if the plain-palatal contrast of fricatives is maintained in the languages of investigation. According to these graphs, all British subjects have lost their [su-sju] contrast with respect to the words 'super' and 'soup'. The F2 confidence intervals of the plain and palatal sequences overlap all along. The [fu-fju] contrast is preserved for all subjects. The F2 formant contours remain apart throughout the entire duration for six subjects. The other two maintain it for a period of 0.14 and 0.15 seconds. There is no loss of contrast in terms of the voiced fricatives. The [vu-vju] contrasts is maintained for a duration of 0.23 seconds, on average, while the F2 contours of the [zu-zju] sequences remain apart for the entire duration.

The Bulgarian and Russian fricative plain-palatalized contrasts are maintained for similar durations in the context of the vowels [u] and [a], like the plosive consonants. Therefore, the summary of scores in Figures 2.49 and 2.50 refers to both vowel contexts.

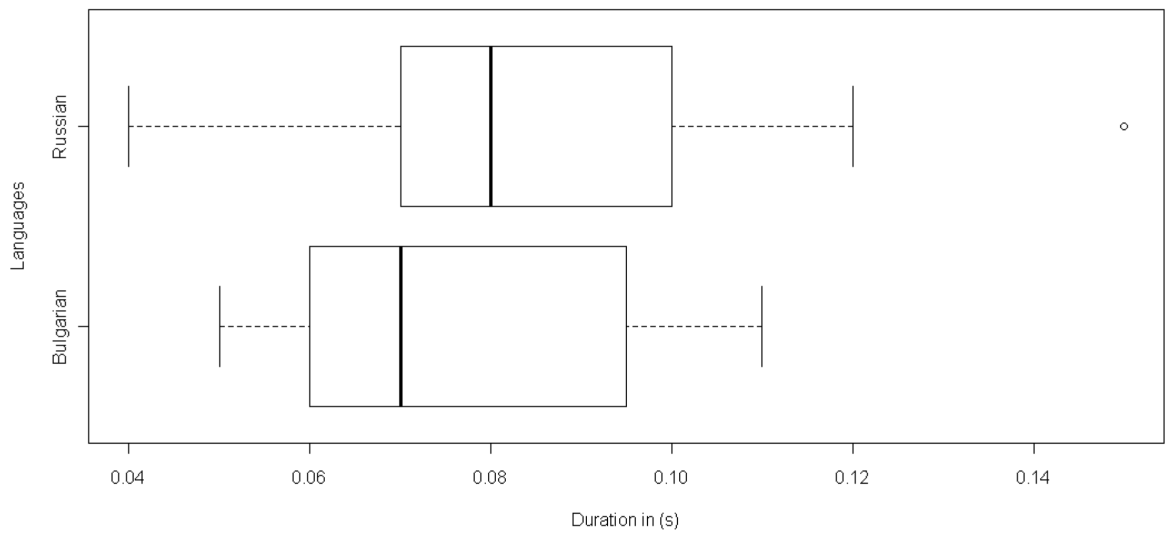


Figure 2.49 Cross-language comparison of the duration of F2 formant contours of voiceless fricative consonants prior to overlapping, in the context of [a u]

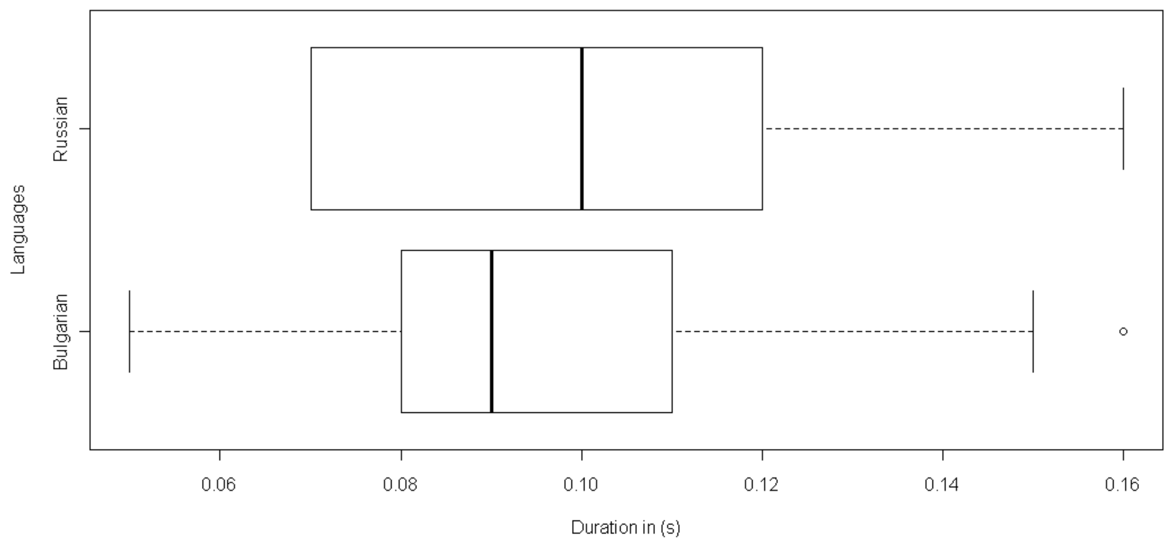


Figure 3.50 Cross-language comparison of the duration of F2 formant contours of voiced fricative consonants prior to overlapping, in the context of [a u

With regards to the voiceless fricatives, most subjects' scores fall between the ranges of 0.06 – 0.10 seconds and 0.07 – 0.10 seconds for Bulgarian and Russian, respectively. In terms of the voiced fricatives, most subjects' scores fall between the ranges of 0.08 – 0.11 seconds and 0.07 – 0.12 seconds for Bulgarian and Russian, respectively. It is unclear as to why the duration of the contrast is slightly higher for the voiced fricative contrasts. Irrespective of this, the scores are similar between the two languages. Furthermore, the situation is not complicated by VOT. Therefore, we can be reasonably confident that the difference among languages consists of the length of the palatal segment. As the data accumulates, it is becoming increasingly likely that palatal segment of Bulgarian is a secondary gesture, as in Russian.

With regards to the nasal consonants, the plain-palatal contrast is preserved in all three languages in the context of the vowel [u]. As the primary gesture of [m] does not involve the tongue, it was possible to measure the duration of the steady state glide portion. The results are identical to those of the other consonants. The average duration is 0.04 seconds for Bulgarian and Russian, and 0.09 seconds for British English. The glide is clearly identifiable on the spectrograms of the Bulgarian and Russian, as well as British subjects. Conversely, the glide is obscured by the antiformants of [n] in the [nju] spectra of the Slavic languages. The time elapsed before the overlap of the plain and palatal confidence intervals is the same, 0.08 seconds median for Bulgarian and Russian, but just over twice as long, in British English, 0.15 seconds median (Figure 2.51).

The nasal plain-palatal contrast is also preserved in the context of [a] for Bulgarian and Russian. The boxplots in Figure 3.52 indicate that most subjects' scores fall within the ranges of 0.09 – 0.11 seconds and 0.08 – 0.11 seconds for Bulgarian and Russian, respectively.

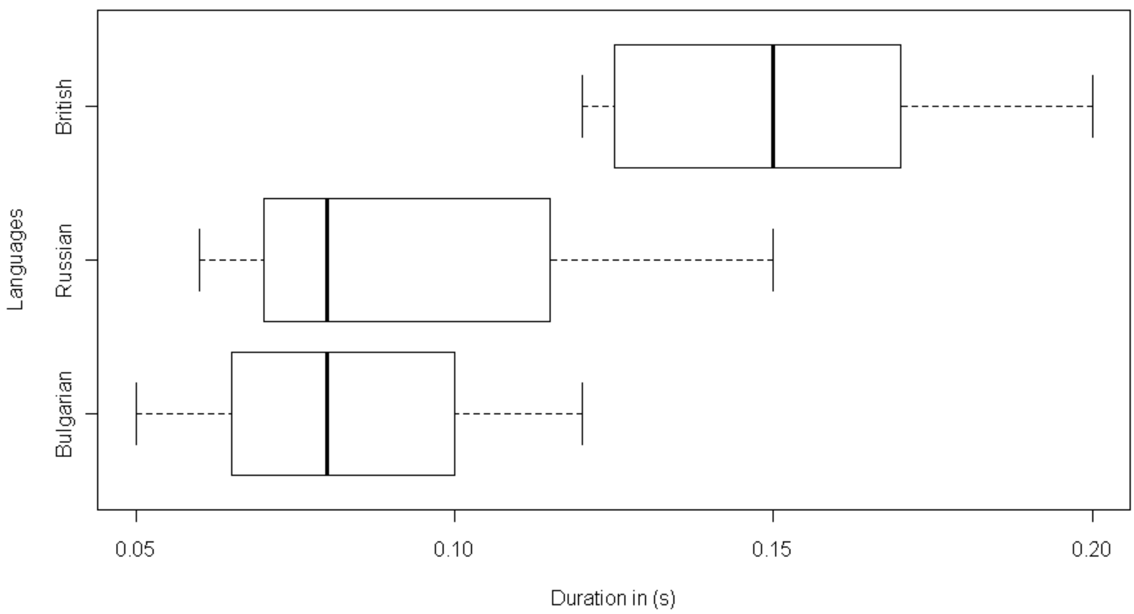


Figure 2.51 Cross-language comparison of the duration of F2 formant contours of nasal consonants prior to overlapping, in the context of [u]

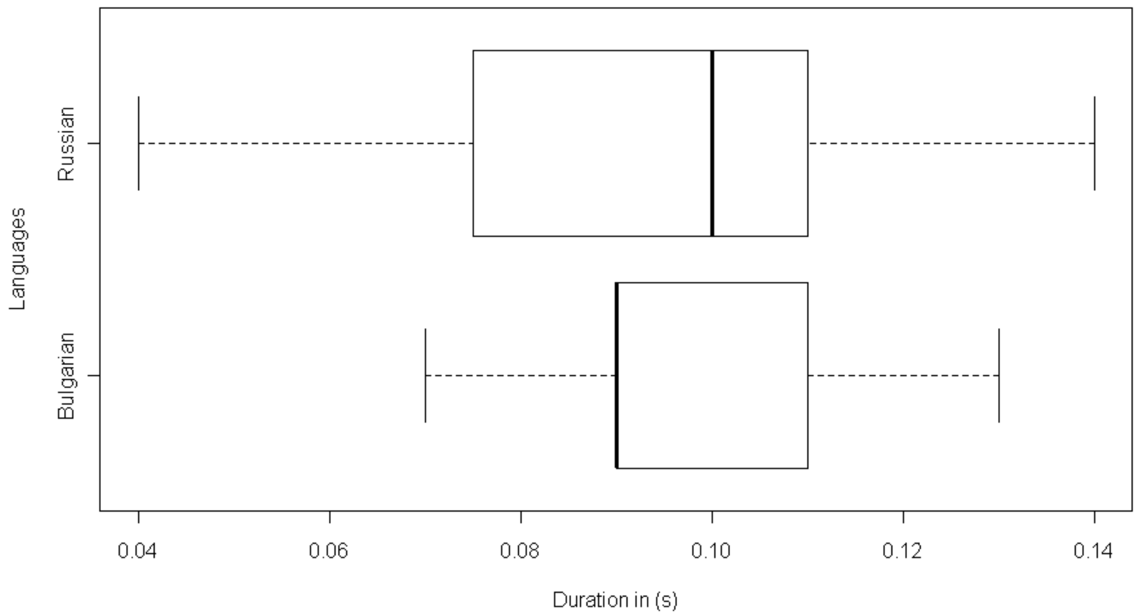


Figure 2.52 Cross-language comparison of the duration of F2 formant contours of nasal consonants prior to overlapping, in the context of [a]

The SSANOVA graphs of the British lateral approximant indicate that the plain-palatal contrast is maintained for all but three subjects. The latter have lost the palatal glide in the pronunciation of 'Luke', as indicated by the overlap of the confidence intervals of F2 formant contours. All Bulgarian and Russian subjects have retained the [l-lʲ] contrast in the context of the vowels [u] and [a]. On the grounds of identical data from the SSANOVA graphs, it is reasonable to assume that Bulgarian has retained the palatalized [lʲ] and no depalatalization has occurred. Both the Bulgarian and Russian [lu-lʲu] F2 formant contours remain distinct for the same duration of 0.05 seconds. Furthermore, the [la-lʲa] contrast is maintained for a similar duration in Bulgarian and Russian, 0.12 and 0.13 seconds, respectively. The SSANOVA graphs are also our prime source of evidence that the Bulgarian and Russian [r-rʲ] contrast in the context of the vowels [a] and [u] has attributes similar to those of the other consonants.

We have now accumulated data from acoustic measurements, the glide duration measure and Smoothing Spline ANOVA statistics, which indicate that the Bulgarian palatal glide is very similar to the Russian palatal glide, and different from the British palatal glide. The main research question asks if the secondary palatal glide gesture of standard Bulgarian has decomposed from the consonant and become a primary articulation in the context of the vowel [u] and [a]. We were able to measure the duration of the palatal glide element following consonants whose primary place of articulation does not involve the tongue. Therefore, any steady state formants following the release of the consonant can be associated with the glide. The results indicate that the British palatal glide has a duration of 0.05, 0.07, and 0.09 seconds in the environment of [p_u], [b_u] and [m_u], respectively. We also know that the British palatal glide is a not a secondary articulation, but an approximant which forms a falling diphthong with the vowel [u] (MacKay, 1987).

The existence of Russian palatalized consonants is uncontroversial. A number of researchers have studied their acoustic and articulatory properties (e.g., Keating (1988); Kochetov (2004); among others). The duration of the secondary palatal gesture of the Russian consonants [p b m], in the context of [u], is 0.02, 0.04, and 0.04seconds, respectively. With the exception of [p_u] (0.03seconds), the palatal glide of Bulgarian has the same durational measures. In the context of [p_a] and [b_a], the glide's duration is 0.03 and 0.04 seconds, respectively. These identical figures indicate that the palatalized consonants of Standard Bulgarian have not undergone depalatalization, and that the palatal glide in the abovementioned environments is a secondary articulation, just like in Russian.

In chapter 1, on the grounds of the available studies (Tilkov, 1983; Richey, 2000), we noted perceptual attributes that point to differences between Bulgarian and Russian palatalized consonants. It seems Bulgarian listeners (Tilkov, 1983) relied on the cues in the transitions with the following vowel to identify a consonant as palatalized. In the context of the current acoustics study, any cues available in the steady state portion of the secondary palatal glide of a palatalized labial consonant, for example, would be insufficient to recognize that consonant as palatalized. A perception study, described in chapter 3, investigated if Bulgarian and Russian subjects needed to hear beyond the duration of the secondary palatal glide in order to recognize palatalized consonants in their respective languages.

Chapter 3

An Audio-Visual Perception Study of Bulgarian and Russian Palatalized Consonants: Audio-Only Condition

3. 1 Introduction

To date, the only study (Tilkov, 1983) to test the perception of Bulgarian palatalized and plain consonants found that Bulgarian listeners needed the formant transitions with the following vowel to identify consonants as palatalized (with the exception of the velars /k^j g^j x^j/). The implication is that the secondary palatal gesture is not enough to cue the perception of these consonants. However, the acoustic study described in chapter 3 provides evidence that the acoustic attributes of Bulgarian and Russian palatalized consonants are very similar. This is important as the Russian subjects of Richey's (2000) experiment did not need the formant transitions to identify the palatalized consonants.

The goal of this perception study is to try to reconcile these potentially conflicting results. To this end, two variations of the gating task (Grosjean, 1980) were employed: auditory only and audio-visual. The audio-visual experiment is described in chapter 5. In a typical gating task, a stimulus is segmented into several portions (gates). Thus, subjects hear a stimulus over a number of gates. At each consecutive gate, there is an increase in the amount of perceptual information. On hearing the stimulus at each gate, subjects record what they have heard and may indicate how confident they are in their response, based on a predetermined ranking scale. As applied to word recognition, the gating task gives an insight as to how much of the percept a subject needs to hear in order to correctly identify a particular word. With respect to the current study, the audio-only and audio-visual gating tasks have the potential to inform us how much auditory and visual information a listener needs in order to identify a consonant as palatalized.

The gating paradigm has generally been employed for studying properties of the mental lexicon. As such, it has been criticized for its ability to tap into on-line perceptual processes (Cutler, 1995). As it is implemented in this study, the gating paradigm constitutes an off-line task: listeners attempt to identify a target after stimulus presentation in the absence of any response deadline. Following the conventions in previous gating experiments, two points along the gating continuum will be of a particular interest, the ‘Isolation Point’ and the ‘Recognition Point’. In traditional terms (Grosjean, 1980; Grosjean, 1996), the ‘Isolation Point’ is defined as the size of segment needed to identify a stimulus correctly; the ‘Recognition point’ is obtained by the size of segment needed to reach a particular level of confidence in subjects’ responses (e.g., 80% confidence for Tyler and Wessels, 1983).

3.2 Hypotheses: Audio-only condition

Based on the acoustic similarities between the Bulgarian and Russian plain and palatalized consonants established in the acoustic study in chapter 2, it was hypothesized that Bulgarian and Russian subjects would identify a consonant as palatalized at a gate which contains cues for palatalization. In accordance with the gating criteria described on page 96, this gate would contain a part of the acoustic information after the release of the consonant and prior to the transitions with the following vowel. On the basis of the acoustic analyses in chapter 2, after the release of the consonant, the palatalization cues are contained in the high energy frication noise which is caused by the constriction created by the tongue raised towards the palate, that is, the secondary palatal articulation. This high energy frication noise, which is similar to that of sibilant fricatives, was observed in both languages. This is interesting as in Stoykov's x-ray studies (1942, 1961) the plain /t d s z l r n/ consonants and their palatalized /tʲ dʲ sʲ zʲ lʲ rʲ nʲ/ counterparts had an identical tongue height. When the tongue is not involved in the primary consonantal articulation, any formant structures prior to the transitions with the following vowel would be associated with the palatal glide as a secondary gesture. Thus, it was also expected that in the case of labial consonants, this part of the acoustic signal would cue the palatalization process.

In terms of the plain consonant, it was hypothesized that subjects would have sufficient cues to identify the consonant correctly at the gate at which contains the transitions with the following vowel and part of that vowel as well.

3.3 Method

3.3.1 Preamble

The method section in this chapter applies to the audio-only and the audio-visual conditions of the main experiment because both conditions follow the same experimental design and apparatus. Furthermore, the same group of Bulgarian and Russian subjects participated in both conditions and experienced the audio-only and audio-visual stimuli which were created by the same criteria. The only difference between the two sets of stimuli is the presence (audio-visual) or absence (audio-only) of visual information.

3.3.2 Design and apparatus

The study employed a within-subject, 1 x 2 (one independent variable; two dependent variables) factorial design. The independent variable is the word presented for perception. There are several levels of the independent variable. In principle, these levels equal the number of gates into which each word is divided. However, for the purpose of this study, only the gates of the word-initial [CV] or [C^jV] of the stimuli were included. The dependent variables are the correct responses and confidence rankings at each gate.

The plain [t d s z l r n] and palatalized [t^j d^j s^j z^j l^j r^j n^j] consonants were included in the experiment. They were selected for the following reason. The plain and palatalized counterparts appear to have identical tongue body height in Stojkov's (1942, 1961) study. As a result, it could be argued that [t^j d^j s^j z^j l^j r^j n^j] have undergone depalatalization, which was defined as a case of the secondary palatal gesture [^{j}] turning into a primary palatal gesture [j]. In addition, [v] and [v^j] were selected in order to have a set of labial consonants which have salient visual cues of place of articulation. The critical segments appear word-initially for both languages and the primary stress falls on the first syllable. The ratio of experimental to distracter stimuli is 1:2, which seemed adequate as none of the participants guessed the purpose of the experiment. Each stimulus was presented only once across gates. The list of stimuli consisted of minimal or near-minimal pairs of plain and palatalized consonants (Appendix 3). For both conditions, audio-only and audio-visual, the stimuli were counterbalanced across two blocks such that plain and palatalized counterparts never occurred in the same block. The order of presentation of the two blocks, and the stimuli within them, was randomized for each subject by the experimental software E-Prime (Schneider, Eschman, & Zuccolotto, 2001).

For each language, the stimuli were produced by two native speakers of Bulgarian and Russian. They were recorded in a soundproof booth in the Sound Patterns Laboratory at the University of Ottawa. Each speaker was seated in a chair with a head rest. They were instructed to read the stimuli at a normal pace off a computer screen. They were asked to close their mouth prior to the production of each word so that audio-visual tokens would be seen with the lips closed at the beginning of each token in the audio-visual conditions. Only the speakers' face, including the chin, was recorded in the video stream. Their productions were recorded with a Shure KSM44A microphone through a USBPre *1.5* preamplifier and a Panasonic PV-GS90P/PC Digital Video Recorder. The audio and visual signals were routed through a jack panel on the sound booth wall to a QuickTime Pro7 player on a Mac computer (Processors: Quad-Core Intel Xeon 2.66 GHz, Graphic card: NVdia GeForce GT120). The parameters for the digital audio recordings were as follows: mono, 44 kHz, 24 bits per sample. The digital video was recorded in QuickTime .mov files at 30 frames per second. Each stimulus word was recorded three times. Only one of the tokens was selected and edited for the experiment.

Recorded stimuli were automatically gated, via a script, at 33 ms duration (the duration of a single video frame). The same gate duration applied to the audio-only and audio-visual conditions. The stimuli were edited in Final Cut Pro 7 (Apple Inc, 2010). For the audio condition, sound files were extracted from the QuickTime .mov files. For the audio-visual conditions, sound files were modified in Praat (Boersma & Weenink, 2008) by reducing the signal-to-noise ratio by 10dB. The SNR was changed by the following procedure. The intensity of the vowel /a/ was measured from the speech files of both speakers. The vowel intensity, which was quite consistent across tokens, was averaged at 72dB for the Russian speaker and 74dB for the Bulgarian speaker. Accordingly, two noise files were generated through the Gaussian function in Praat, each with a different intensity, 62dB and 64dB. The SNR was calculated with the formula dB S/N = S – N (e.g., dB S/N = 74 - 64 = 10 (Speaks, 1999)). The noise files were generated the same length as the original sound files and with the same parameters (mono, 44 kHz, 24 bits per sample), then combined with them. The purpose of impairing the sound quality was to encourage subjects to attend to visual information. The modified sound files were aligned with the video files in Final Cut Pro 7 (Apple Inc., 2010). All three tokens of each audio-visual stimulus were inspected across all gates, frame by frame.

One of these tokens was chosen for the experiment based on the following acoustic criteria:

1. For palatalized consonants, the gate associated with palatalization should contain the signal immediately after the release of the consonant; moreover, this gate could not include the transitions with the following vowel as it was important to establish if Bulgarian subjects, in particular, would need this cue to perceive a consonant as palatalized.
2. For plain consonants, the first gate associated with the vowel should include the signal immediately after the release of the consonant.

As the tokens were produced naturally, the duration of the audio signal which included the initial CV or C^jV sequences of each token varied in time. Consequently, a consonant was segmented from a minimum of two gates to a maximum of six gates. Fricative consonants tended to have the most gates. The pre-release portion, or the closure, of plosive consonants was segmented into three to four gates. In the audio-only condition, subjects heard no audio signal for the entire duration of these gates. However, in the audio-visual condition, subjects had visual cues available. The burst, or the release portion, of plosive consonants was always joined with some period of the consonantal closure. Only for a handful of words, none of the three tokens allowed for the burst to be part of the consonant closure. For instance, this was the case of the Bulgarian word /t^jula/ where the burst was joined with a portion of the palatalization. This meant that the following gate contained a portion of the palatalization and the transitions of the following vowel (Figure 3.3.a., page 100). The acoustic information of palatalized consonants could, in some instances, span over two consecutive gates (Figure 3.3.c, page 100). The palatalized portion of some palatalized consonants was segmented such that some of it spanned an entire gate with a consecutive gate containing the rest of it plus the transitions with the following vowel (Figure 3.3.b, page 100). Vowels were segmented from two to four gates. Given the variable number of gates associated with consonants and vowels, subjects could heard from five to twelve gates for each CV or C^jV sequence. Only the initial CV or C^jV gates of each token were presented to the subjects as it was hypothesized that this would give them enough information to identify a consonant as plain or palatalized. In both the audio-only and audio-visual conditions, the gates of all tokens had the same time points as determined by the acoustic criteria mentioned above. Finally, the original QuickTime .mov files were converted to .avi files as this was the format required by 'E-Prime2', the presentation software.

3.3.3 Participants

Twenty native speakers of Standard Bulgarian (22 – 72 years old; Mean = 35; SD = 11) and twenty-two native speakers of Standard Russian (21 – 65years old; Mean = 34; SD = 12) took part in the experiment. They had completed their primary and secondary education in their respective countries prior to coming to Canada. All maintained their native languages at home and in their native communities. All of them signed an informed consent form prior to taking part in the experiment. None of them reported any hearing problems and had normal or corrected-to-normal vision. They were paid $20.00 for their participation in the experiment, which lasted about an hour. Each subject participated in both the audio-only and audio-visual conditions on the same day. Some started with the audio-only condition and others with the audio-visual condition. This order was determined through a counterbalanced ABBA procedure. Participants took a break before commencing their second condition. None of them took more than five minutes, although they were informed that they could rest for as long as they needed.

3.3.4 Procedure

Participants were tested individually at one of the testing stations in the Sound Patterns Laboratory at the University of Ottawa. They were seated comfortably, about 50cm away from a Toshiba laptop placed in front of them. The laptop had the following specifications: 17 inch monitor with a resolution of 1600 x 900 pixels, CPU – Intel Mobile Core 2 Duo T66600 @ 2.20GHz, Graphics – Mobile Intel(R) 4 Series Express Chipset Family, Audio – High Definition Audio Device, OS – MS Window 7 Home Premium 64-bit. Auditory stimuli were presented over KOSS PRO4AA stereophone at a similar comfortable hearing level.

All subjects began with a practice session to become familiar with the experimental procedure. The practice session included three gated tokens. The experimental session lasted about 25 minutes. The experiment involved a forced choice identification task with the following procedure:

1. A minimal or near-minimal pair (for example, [val, vʲal]) appeared in the centre of the computer screen;
2. Then, a '+' symbol appeared for one second in the middle of the screen to signal the appearance of the audio or audio-visual stimuli;
3. Subjects heard (audio-only conditions) or heard and saw (audio-visual condition) the information from a gate, always beginning from gate one;
4. Afterwards, the pair of words was shown again on the computer screen. Subjects were asked to choose the word associated with the presented stimulus. They pressed the 'A' key if they chose the word on the left and the 'L' key if they chose the word on the right. They were encouraged to make a guess if they were not sure which word to select;

5. Following their selection, subjects rated how confident they were in their response on a scale of one to four (1-very sure, 2-fairly sure, 3-fairly unsure, 4-very unsure).

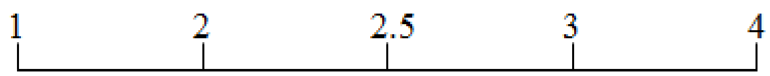
This cycle continued until they heard all gates of each stimulus. In each condition, subjects from both languages heard the initial CV or C^jV portion of 42 words. In both the audio-only and audio-visual condition, Bulgarian and Russian participants had 333 trials and 251 trials, respectively. The number of trials corresponds to the number of gates from all words. Some Russian words were shorter in duration which resulted in the lower number of trials.

3.4 Statistical Analyses

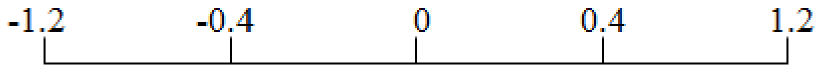
3.4.1 Descriptive Statistics

All statistical analyses were performed with R (version 2.13.1). Each subject's confidence rankings for all the gates of each stimulus were converted into z-scores in order to standardize them. Subsequently, the standardized rankings of the gates of a stimulus were plotted with a series of boxplots. To aid the interpretation of these boxplots, a comparison of the original and standardized ranking scale is given below. The mean and standard deviation of the numbers of the original scale were used in the z-scores formula to derive the standardized z-score values. Averaged subjects' z-scores were interpreted against this scale.

- Original ranking scale, used by the subjects during the experiment.



- Standardized ranking scale, used for the statistical analyses and interpretation of results.



Please note that both scales are ordinal in that they reflect the order of confidence ratings from very sure (1) to very unsure (4). While no information about the distance between the numbers is available, this type of scale allows us to determine positional statistics as the mean, median, quartile and percentiles. The mean and median for the scales above are 2.5 and 0 for the original and standardized scales, respectively. The numbers on the standardized scale have been rounded. The numbers prior to rounding are as follows: -1.16189540772459, -0.38729846924153, 0, -0.38729846924153, 1.16189540772459. In addition to confidence rankings, subjects' correct responses for the relevant gates were calculated in percent. We will discuss how these gates were determined in the overview of the results section.

3.4.2 Inferential Statistics

Following the descriptive statistical analyses, a one way repeated measures ANOVA on subjects' confidence rankings was conducted, with a Gate Factor. Three gates, or three levels of the independent variable, were included in the analyses. These were the Initial Gate, the Isolation Gate and the Recognition Gate. The Initial Gate served as a reference point in determining if there was a change in the level of confidence in subjects' responses from the beginning of the word. Furthermore, the Isolation Gate was determined on the basis of subjects' correct responses. It turned out that at this gate there was a sharp rise in subjects' confidence ratings as indicated by the boxplots of confidence ratings at each gate of each tested consonant (e.g., Figures 3.2.a-d, page 98). The highest level of confidence was observed at the last gate of each consonant, the Recognition points. It was interesting to see if the difference in confidence ratings between the Isolation and Recognition points was statistically significant.

The repeated measures ANOVA was performed with the *anova* function from the *car* package (Fox &Weisberg, 2011) in R. The benefit of using this function is that the ANOVA analyses assume sphericity. A Repeated Measures ANOVA is susceptible to the violation of the sphericity assumption. Sphericity is the condition where the variances of the differences between all combinations of the related levels of the independent variable are equal (Kirk, 1995). This is particularly relevant to research designs in which there are more than two levels of the independent measures. A violation of sphericity increases the likelihood of a *Type I error* which means a likely failure in rejecting the *Null Hypothesis*. Max and Onghena (1999) have noted that very few studies of speech and hearing research acknowledge the sphericity assumption.

In the current study, three levels of the independent variable are being considered (Initial, Isolation, Recognition Gates). Therefore, it is important to test for violation of the sphericity assumption. The *anova* function from the *car* package (Fox &Weisberg, 2011) in R performs a *Univariate Repeated-Measures ANOVA Assuming Sphericity*. That is, the ANOVA analysis is followed by the *Mauchly Test for Sphericity* (Mauchly, 1940) and the *Greenhouse-Geisser Corrections for Departure from Sphericity* (Greenhouse and Geisser, 1959). Sphericity is violated when the significance level of *Mauchly's Test* is < 0.05. If the *Mauchly Test* indicates violation of sphericity, then the corrected p-value from the *Greenhouse-Geisser* corrections is considered relevant. In simple terms, the *Greenhouse-Geisser* procedure estimates the degree to which sphericity has been violated and applies a correction factor to the degrees of freedom of the F-distribution.

Following the results from the ANOVA, post-hoc analyses were performed with the *pairwise.t.test* function from the *stats* package in R. This function is also part of the *car* package in R. It calculates pairwise comparisons between group levels with corrections for multiple testing. P-values were adjusted by the *Holm method* (Holm, 1979) which was designed to give strong control of the family-wise error rate (Yoav & Hochberg, 1995).

3.5 Results: Audio Only Condition

3.5.1 Overview of the Results:

As this is a cross-language comparison study, the results for Bulgarian and Russian are presented simultaneously. In this study, the gating experiment was adopted as perceptual information could be presented incrementally, with an increase at each consecutive gate. This procedure allows us to determine how much information is necessary to identify a word correctly. Accordingly, two points along the gating continuum are considered important, the Isolation Point and the Recognition Point. Following Grosjean (1980, 1996), we will define the Isolation point as the size of segment needed to identify a stimulus correctly. In other words, this would be the gate at which subjects correct responses will be well above chance. As correct responses are calculated in percentage, a strong figure would be anything between 80 % and 100%. We should note that at the Isolation Gate, subjects' confidence ratings may not be very high as the word is only partially heard. The Recognition Point is obtained by the size of segment needed to reach a high level of confidence in subjects' responses. As Grosjean (1996) notes, researchers do not have consistent criteria according to which to determine this level of confidence. For example, Tyler and Wessels (1983) defined the Recognition Point as the gate at which a confidence of 80% is reached.

In this study, two Isolation Points emerged: (1) for plain consonants, the gate which contained the first potion of the following vowel; (2) for palatalized consonants, the gate containing the acoustic information for palatalization. Importantly, for both languages and both types of consonants, subjects' accuracy rates reached at least 95%. As mentioned before, subjects are not expected to have a high degree of confidence at the Isolation Point as they have heard the word only partially (Grosjean, 1996). However, in this study, Bulgarian and Russian participants rated the majority of the consonants with at least –0.4, but often as high as –0.9 on the standardized rating scales. That is their level of confidence was verbalized as 'fairly sure', but also approaching 'very sure'.
The Recognition point turned out to be the gate containing the last portion of the vowel following the initial consonant. At this gate, subjects had enough information about the stimulus to feel most confident in their choice of word. In addition, the accuracy of their responses was at least 95%, but more often reached 100%.

3.5.1.1 Plosive Consonants [t d t^j d^j] in the Context of the Vowel [a].

Figures 3.2.a – d contain boxplots which represent the confidence rating of Bulgarian and Russian subjects for the plain consonants /t d/ in the environment of the vowel [a], across all gates. Recall that only the initial CV and C^jV of each word were presented for perception. Recall also that each consecutive gate contains the perceptual information from the preceding gates. The graphs consist of two axes: (1) the gates span on the horizontal axis, and (2) the standardized confidence ratings on the vertical axis. Negative values indicate more confidence than positive values. Any shift from the mean (0) to the negative values on the vertical axis indicates an increase in confidence. The consonantal portion prior to the burst consists of the closure period. For both languages, there is a dramatic increase in the level of confidence for the plain [t d] at the gate which includes the first portion of the vowel. This also includes the transitions between the consonants [t d] and vowel [a]. It was hypothesized that for plain consonants this would be the Isolation Gate, the point at which they can identify a consonant as plain or palatalized.

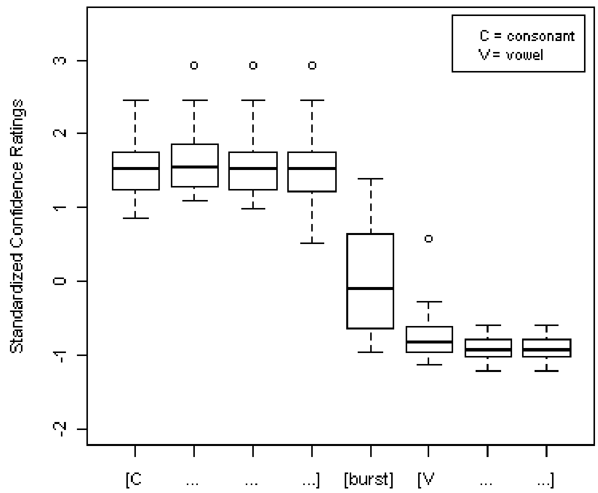


Figure 3.2.a. Boxplots of Confidence Rankings of all gates of Bulgarian [tam], Audio Condition.

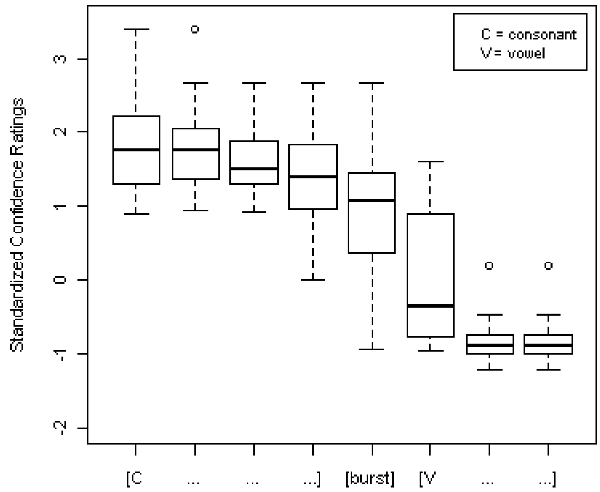


Figure 3.2.b. Boxplots of Confidence Rankings of all gates of Russian [tak], Audio Condition.

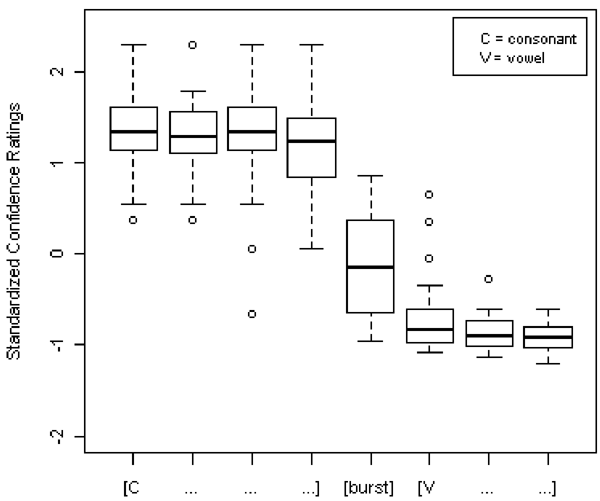


Figure 3.2.c. Boxplots of Confidence Rankings of all gates of Bulgarian [dava], Audio Condition.

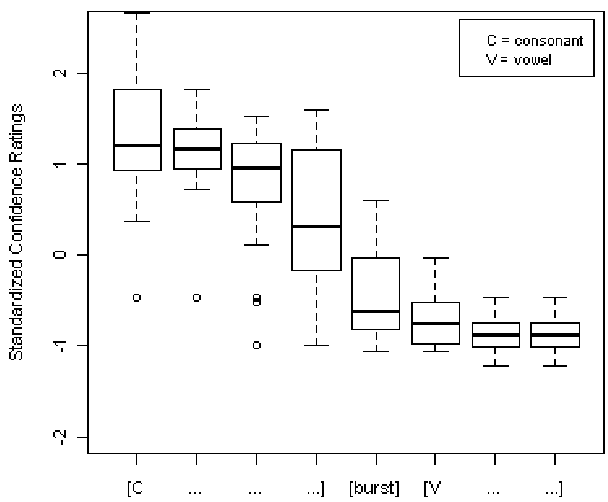


Figure 3.2.d. Boxplots of Confidence Rankings of all gates of Russian [datelj], Audio Condition.

It was also expected that subjects would achieve high accuracy rates at this point in the perception process. In terms of the [ta] sequence, for the Isolation Gate and all subsequent gates, the Bulgarian participants achieved an accuracy rate of 95%. For the same sequence, the Russian participants showed an accuracy of 91% for the Identification Gate and 100% for the gates thereafter. For the [da] sequence, from the Isolation Gate onwards, Russian and Bulgarian subjects showed an accuracy of 100% and 95%, respectively.

Figures 3.3.a – d show boxplots of confidence ratings of Bulgarian and Russian subjects of the palatalized consonants [t^j d^j] across all gates. According to the information in the boxplots, both groups of subjects are ‘fairly sure’ in their responses at the gate which contains the information on palatalization, and this applies to the [t^ja] and [d^ja] sequences. Bulgarian subjects hear palatalization over two gates for the [d^ja] sequence. At the point of the second palatalization gate, they are ‘very sure’ of their responses and this level of certainty is repeated for all subsequent gates which contain perceptual cues about the vowel [a]. Subjects from both languages can identify a [tja] sequence at the Isolation Gate with an accuracy of 95%. All subsequent gates a recognized with an accuracy of 95% and 100% for Bulgarian and Russian, respectively. Both groups of subjects show a similar accuracy percentage for the [d^ja] sequence. At the Isolation Gate, where the palatalization cues become available, as well as all subsequent gates, Russian listeners are 100% accurate in their choice. Bulgarian listeners achieved an accuracy of 75 % at the first [pal] gate. However, at the second [pal] gate, they are 100% accurate in their choice of consonant. The same accuracy rate applies for the remainder of the gates for the sequence [d^ja].

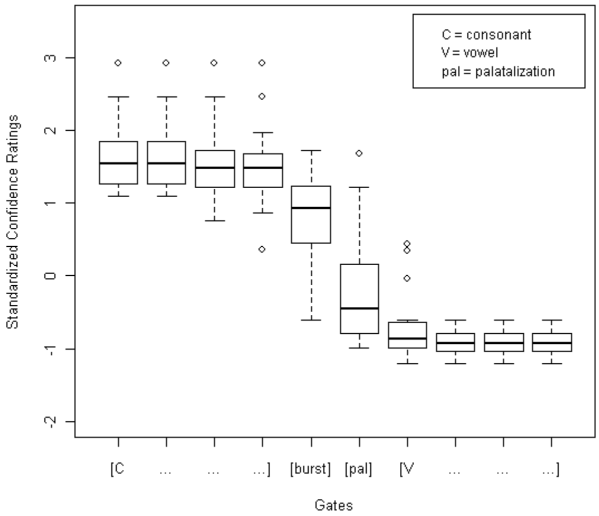


Figure 3.3.a. Boxplots of Confidence Rankings of all gates of Bulgarian [t^{j}am], Audio Condition.

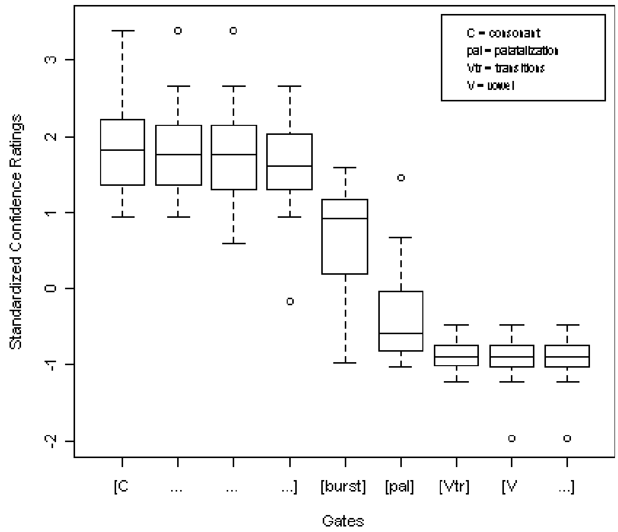


Figure 3.3.b. Boxplots of Confidence Rankings of all gates of Russian [t^{j}ag], Audio Condition.

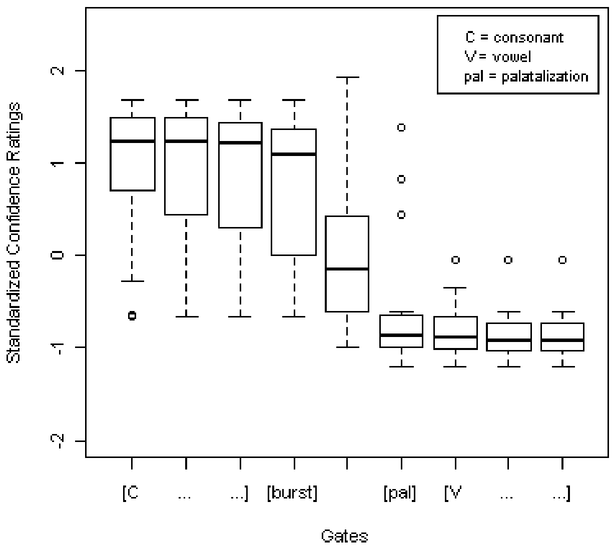


Figure 3.3.c. Boxplots of Confidence Rankings of all gates of Bulgarian /d^{j}ava/, Audio Condition.

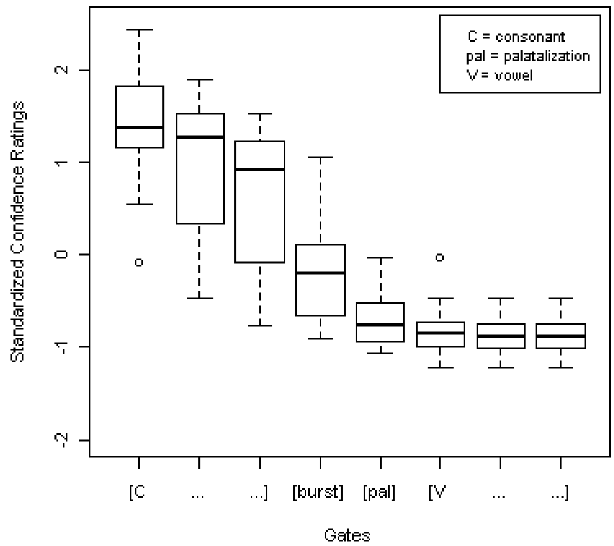


Figure 3.3.d. Boxplots of Confidence Rankings of all gates of Russian /d^{j}atel/, Audio Condition.

Table 3.1 presents the mean, range and standard deviation for the Bulgarian plosives. As mentioned before, the Isolation Gate contains the palatalization cues for palatalized consonants and vocalic cues for the plain consonants. The second Isolation Gate contains the remainder of the palatalization cues for [d^j]. The Recognition Gate contains the entire vocalic information for both types of consonants. As the mean confidence rates increase across gates, separate One-Way Repeated Measures ANOVAs (assuming sphericity) with a gate as factor were performed.

Table 3.1. Confidence Ratings (in z-scores) for Plosive Consonants, [a] Context, Audio Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/t/	20	1.56	1.59	0.40	- 0.70	1.75	0.40	- 0.91	0.60	0.18
/tʲ/	20	1.66	1.82	0.47	- 0.15	2.65	0.83	- 0.90	0.58	0.17
/d/	20	1.35	1.92	0.46	- 0.65	1.75	0.47	- 0.90	0.58	0.17
/dʲ/	20	0.97	2.36	0.74	0.04	2.91	0.83	- 0.86	0.26	1.15
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/dʲ/	20				- 0.62	2.60	0.69			

The analyses revealed a main effect of Gate for all consonants (Table 3.2). The Mauchly Test indicated that the sphericity assumption was violated for all but one factor, the [d] Gates. Therefore, the 'Greenhouse-Geisser Corrections for Departure from Sphericity' was performed. It returned the p-values in the column 'Pr(>F[GG])'. Note that the probability values remained unchanged.

Table 3.2. Repeated Measures ANOVA of Confidence Ratings for Plosive Consonants, [a] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/t/ Gates	2, 38	367	< 0.001 ***	p = 0.31	< 0.001 ***
/tʲ/ Gates	2, 38	91	< 0.001 ***	p = 3.8438e-07	< 0.001 ***
/d/ Gates	2, 38	182	< 0.001 ***	p = 0.174	< 0.001 ***
/dʲ/ Gates	2, 38	46	< 0.001 ***	p = 0.796	< 0.001 ***
'R' Significance Codes:	'***' 0.001	'**' 0.01	'*' 0.05	'.' 0.1	' ' 1

Pairwise comparisons of the [t] Gates ($F(2,38) = 367$, $p < 0.001$) indicated that the mean confidence rankings at the Initial Gate was significantly lower than those at the Isolation Gate ($p < 0.001$) and the Recognition Gate ($p < 0.001$). The higher mean confidence rate for the Recognition Gate, compared to the Isolation Gate, is not statistically significant ($p = 0.54$). Pairwise t-tests for the [d] Gates ($F(2,38) = 182$, p < 0.001) showed that subjects' higher confidence in their responses at the Recognition Gate, compared to the Isolation Gate only approached statistical significance (p = 0.048). Confidence level at the Initial Gate was significantly lower than that at the Isolation Gate (p < 0.001) and the Recognition Gate (p < 0.001).

Pairwise comparisons of the [t^j] Gates ($F(2,38) = 91$, $p < 0.001$) showed that the mean confidence rankings at the Initial Gate were the lowest (Initial vs. Isolation, p < 0.001; Initial vs. Recognition, p < 0.001). The mean difference between the Isolation and Recognition Gates approached statistical significant (p = 0.021). The same trend of an increase of mean confidence rankings with an increase of perceptual information was observed with regards to the [d^j] Gates ($F(2,38) = 91$, $p < 0.001$); Initial vs. Isolation (1), p = 0.0001; Initial vs. Isolation (2), p < 0.001; Initial vs. Recognition, p = 0.0001; Isolation (1) vs. Isolation (2), p = 0.005). However, the difference in confidence means between the Isolation (2) and Recognition Gates did not achieve statistical significance (p = 0.253).

Table 3.3 presents the mean, range and standard deviation for the Russian plosive consonants.

Table 3.3. Confidence Ratings (in z-scores) for Plosive Consonants, [a] Context, Audio Condition, Russian subjects.

		Initial Gate			**Isolation Gate (1)**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/t/	22	1.86	2.88	0.75	-0.06	2.57	0.86	-0.81	1.42	0.30
/t^j/	22	1.84	2.45	0.61	-0.37	2.49	0.63	-0.90	1.51	0.31
/d/	22	1.30	3.13	0.72	-0.74	1.03	0.28	-0.85	0.76	0.20
/d^j/	22	1.37	2.51	0.53	-0.73	1.03	0.29	-0.85	0.76	0.20
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/t^j/	22				-0.85	0.76	0.20			
/d^j/	22				-0.81	1.19	0.26			

Given the differences in mean confidence rankings among the critical gates, separate One-Way Repeated Measures ANOVAs (assuming sphericity). As Table 3.4. shows, for all of the consonants, there was a main effect of Gate. The analyses show that the Mauchly Test did not indicate any violation of the sphericity condition as the p-values were smaller than 0.05 (Table 3.4).

Table 3.4. Repeated Measures ANOVA of Confidence Ratings for Plosive Consonants, [a] Context, Audio Condition, Russian subjects.

Factor	**df**	**F**	**Pr(>F)**	**Sphericity Test**	**Pr(>F[GG])**
/t/ Gates	2, 42	367	< 0.001 ***	p = 0.0005	NA
/tʲ/ Gates	3, 63	229	< 0.001 ***	p = 3.4375e-06	NA
/d/ Gates	2, 42	148	< 0.001 ***	p = 3.3655e-05	NA
/dʲ/ Gates	3, 63	239	< 0.001 ***	p = 1.4002e-6	NA
'R' Significance Codes:	'***' 0.001	'**' 0.01	'*' 0.05	'.' 0.1	' ' 1

At the Isolation Gate, subject's confidence in their choice of response increases ([t], Initial vs. Isolation, p< 0.001; [d], Initial vs. Isolation, p< 0.001; [tʲ], Initial vs. Isolation (1), p< 0.001; [dʲ], Initial vs. Isolation (1), p< 0.001). There is an increase in confidence level at the Recognition Gate of [t] (Isolation vs. Recognition, p< 0.001), but not at the Recognition Gate of [tʲ] (Isolation (2) vs. Recognition, p = 0.758). Pairwise t-tests show that the mean difference in subjects' confidence ratings for the consonants [d] and [dʲ] is not statistically significant beyond the Isolation gate ([d] Isolation vs. Recognition, p = 0.41; [dʲ], Isolation (1) vs. Isolation (2), p = 0.9; Isolation (1) vs. Recognition p = 0.71, Isolation (2) vs. Recognition, p = 0.9).

3.5.1.2. Plosive Consonants [t d tʲ dʲ] in the Context of the Vowel [u].

Figures 3.4. a – d represent boxplots of the confidence ratings of Bulgarian and Russian subjects for the gated consonants [t] and [d] in the environment of the vowel [u]. As the boxplots show, for both languages, subjects have an increased level of confidence at the point at which they hear a portion of the vowel formants. At the first [V] gate, which also includes the transitions between the consonant and the vowel, they are 'fairly sure' of their responses. This is also the Isolation Gate for these consonants, for both languages. At this point, the accuracy of their responses is at least 95%. For all subsequent gates, including the Recognition Gate, the accuracy of their responses reaches 100%.

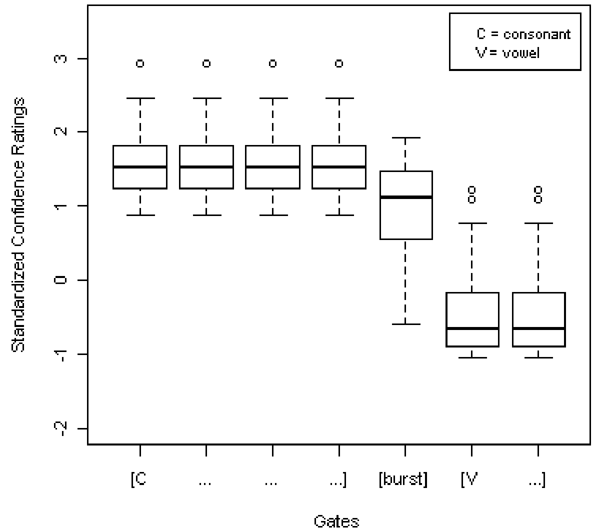


Figure 3.4.a. Boxplots of Confidence Rankings of all gates of Bulgarian [tula], Audio Condition.

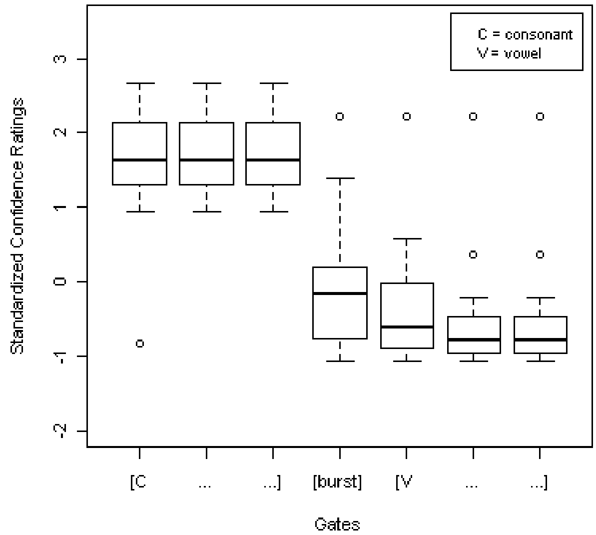


Figure 3.4.b. Boxplots of Confidence Rankings of all gates of Russian [tuk], Audio Condition.

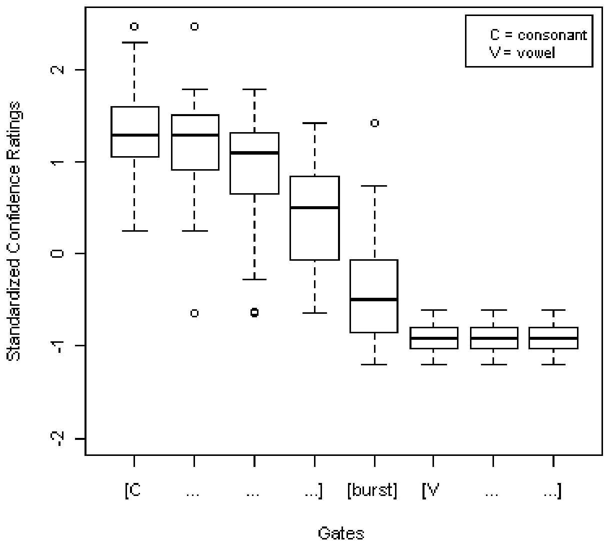


Figure 3.4.c. Boxplots of Confidence Rankings of all gates of Bulgarian [dunav], Audio Condition.

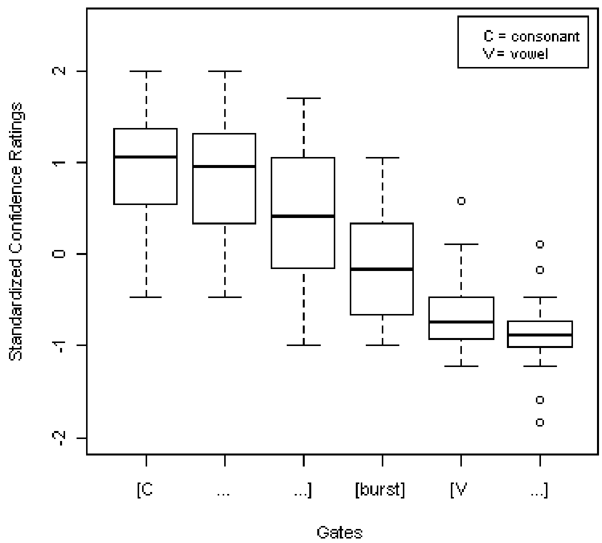


Figure 3.4.d. Boxplots of Confidence Rankings of all gates of Russian [dunutj], Audio Condition.

The Bulgarian and Russian palatalized consonants [t^j d^j], like their plain counterparts, are also recognized with a high degree of accuracy at the Identification Gates. Specifically, as the perceptual cues for palatalization become available, subjects identify them with at least 95% accuracy. As Figure 3.5.(a) shows, the palatalization portion of the consonant [t^j] is straddled between two gates, [burst] and [Vtr], as mentioned before (page 90). Regardless, subjects can identify the consonant as palatalized as early as gate [burst] with an accuracy of 100%. Bulgarian subjects have the same percent of accuracy for the rest of the gates, including the Recognition Gate. The consonant [d^j] is also correctly (100%) recognized as palatalized at the [pal] gate (Isolation Gate). This performance is repeated over the following gates, including the Recognition Gate (100%). The results of the Russian group are identical to the Bulgarian group. Russian palatalized consonants [t^j] and /d^j/, are identified with an accuracy of 95% at the [pal] gate (Isolation Gate). This degree of accuracy occurred throughout subsequent gates, 95% and 100% for /t^j/ and /d^j/, respectively. The boxplots in Figures 3.5. a – d indicate that subjects are 'fairly sure' of their responses at the Isolation Gate. As some vowel information becomes available at the first [V] gate, they become 'very sure' of their responses. Bulgarian subject are not very confident in their responses at the [burst] gate as only partial information of palatalization is available at this point (Fig. 3.5.a).

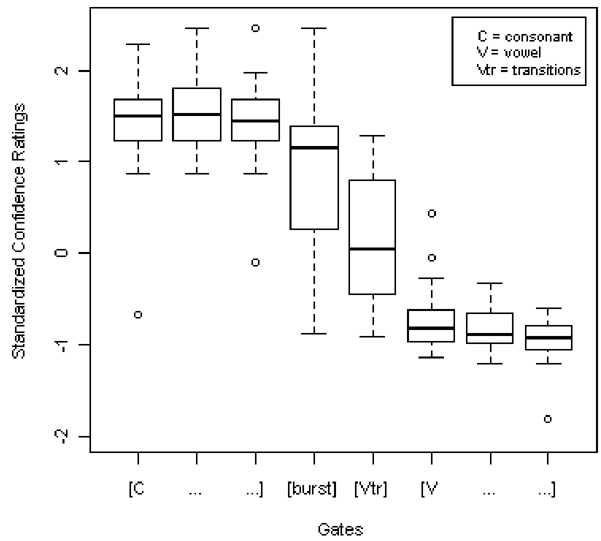


Figure 3.5.a. Boxplots of Confidence Rankings of all gates of Bulgarian [t^jula], Audio Condition.

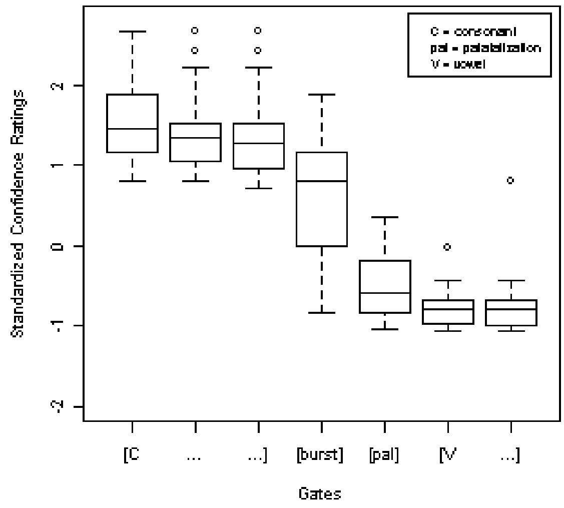


Figure 3.5.b. Boxplots of Confidence Rankings of all gates of Russian [t^juk], Audio Condition.

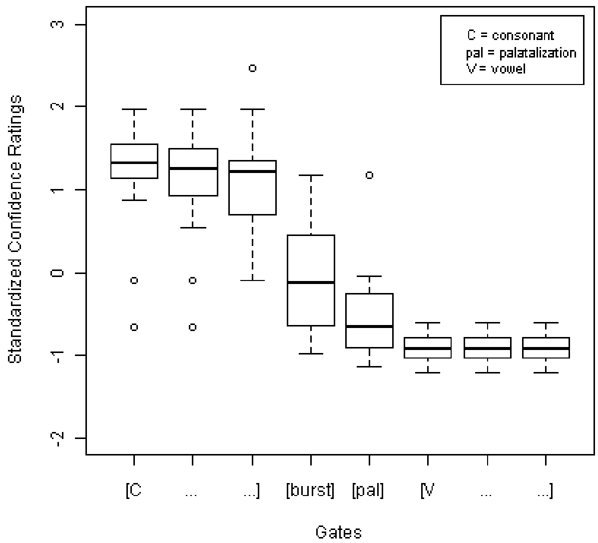


Figure 3.5.c. Boxplots of Confidence Rankings of all gates of Bulgarian [d^juna], Audio Condition.

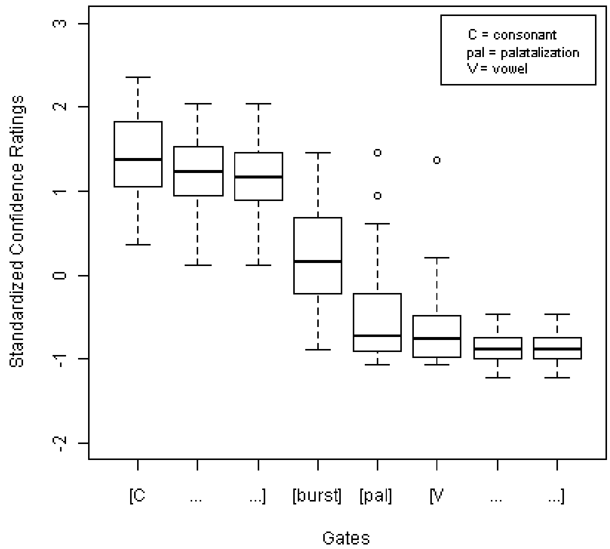


Figure 3.5.d. Boxplots of Confidence Rankings of all gates of Russian [d^juna], Audio Condition.

Tables 3.5 and 3.6, below, show the mean differences in confidence ratings for the consonants [t], [t^j], [d] and [d^j] in the context of the vowel [u].

Table 3.5. Confidence Ratings (in z-scores) for Plosive Consonants, [u] Context, Audio Condition, Bulgarian subjects.

		Initial Gate			**Isolation Gate (1)**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/d/	20	1.02	3.35	0.73	- 0.12	2.50	0.73	- 0.95	1.70	0.37
/d^j/	20	1.21	2.64	0.61	- 0.55	2.32	0.53	- 0.91	0.59	0.18
/t/	20	0.31	2.81	0.92	- 0.17	2.26	0.69	- 0.44	2.82	0.75
/t^j/	20	1.45	3.59	0.68	- 0.19	2.20	0.73	- 0.95	1.20	0.27
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
					- 0.66	1.58	0.46			

Table 3.6. Confidence Ratings (in z-scores) for Plosive Consonants, [u] Context, Audio Condition, Russian subjects.

		Initial Gate			**Isolation Gate (1)**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/t/	22	1.62	3.49	0.74	- 0.39	3.29	0.76	- 0.60	3.29	0.71
/t^j/	22	1.57	1.85	0.52	- 0.49	1.40	0.41	- 0.73	1.87	0.40
/d/	22	0.94	2.46	0.65	- 0.61	1.80	0.45	- 0.85	1.94	0.41
/d^j/	22	1.48	3.02	0.64	- 0.45	2.52	0.68	- 0.85	0.76	0.20

In order to establish if the mean differences in confidence level between the critical gates (Initial, Isolation, and Recognition) have statistical significance, separate Repeated Measures ANOVAs (Assuming Sphericity) with a 'Gate' Factor were conducted. The results from the analyses are in Table 3.7. and Table 3.8 for Bulgarian and Russian, respectively. It is clear that there is a significant effect of Gate in the perception of these consonants. The Mauchly test was conducted to test for violation of sphericity. Where the sphericity assumption was violated, the 'Greenhouse-Geisser Correction for Departure from Sphericity' was applied. Note that the corrected p-values have remained the same.

Table 3.7. Repeated Measures ANOVA of Confidence Ratings for Plosive Consonants, [u] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/t/ Gates	2, 38	367	< 0.001 ***	p = 0.31	< 0.001 ***
/t^j/ Gates	2, 38	75	< 0.001 ***	p = 0.136	< 0.001 ***
/d/ Gates	2, 38	182	< 0.001 ***	p = 0.174	< 0.001 ***
/d^j/ Gates	2, 38	46	< 0.001 ***	NA	NA

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Note – Sphericity requirement for the [d^j] Gates is met as the Isolation & Recognition gates have the same numeric vector.

For the Bulgarian group ($F(2,38) = 367$, $p< 0.001$), pairwise comparisons show that for /t/, subjects level of confidence is much higher at the Isolation Gate than at the Initial Gate. The same is true of [d], $F(2,38) = 182$, $p< 0.001$). The mean difference between the Isolation and Recognition Gates is not statistically significant for plain consonants ([t], $F(2,38) = 367$, $p = 1$; [d], $F(2,38) = 182$, $p = 1$). It is also not significant for [t^j] ($F(2,38) = 75$, $p = 0.074$) and it approaches significance for ([d^j], $F(2,38) = 46$, $p = 0.021$).

Pairwise t-tests for the mean difference in confidence rating between the Initial and Isolation Gates yielded the same results for the Russian plain [t] ($F(2,38) = 116$, $p < 0.001$) and [d] ($F(2,38) = 148$, $p < 0.001$). Identical to the Bulgarian group, mean differences in confidence levels between the Isolation and Recognition Gates of [t^j]($F(2,38) = 153$, $p = 0.08$) and [d^j] $F(2,38) = 0.02$) did not turn out to be significant.

Table 3.8. Repeated Measures ANOVA of Confidence Rankings for Plosive Consonants, [u] Context, Audio Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/t/ Gates	2, 42	116	< 0.001 ***	p = 0.0004	NA
/t^j/ Gates	2, 42	153	< 0.001 ***	p = 0.702	< 0.001 ***
/d/ Gates	2, 42	148	< 0.001 ***	p = 3.3655e-05	NA
/d^j/ Gates	2, 42	166	< 0.001 ***	p = 0.588	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.5.1.3 Summary of Results for Plosive Consonants [t d t^j d^j] in the Context of the Vowels [a] and [u].

The results are identical for both groups, Bulgarian and Russian. Subjects perceive the tested plosive consonants as plain or palatalized at the Isolation Gate. Moreover, the accuracy in the choice of their response is at least 95%. There is a dramatic increase in confidence at the Isolation Gate, compared to the Initial Gate. As the boxplots show, at the Isolation Gate, they are 'fairly sure' in the accuracy of their responses. Neither Bulgarian, nor Russian, listeners need the transitions with the following vowel to identify a consonant as palatalized. Importantly, the mean difference in confidence rating between the Isolation Gate and the Recognition Gate in not statistically significant, or only approaches statistical significance. The vowel context, [a] or [u], does not seem to influence the results.

3.5.1.4 Fricative Consonants [v s z v^j s^j z^j] in the Context of the Vowel [a].

Words in which plain and palatalized consonants occur word-initially next to the vowel [a] are perceived with high accuracy by Bulgarian and Russian listeners at the Isolation Gate. As soon as the perceptual cues of palatalization become available at gate [pal], Bulgarian and Russian subjects achieve an accuracy of at least 95%. They show the same high precision in selecting a plain consonant at the first [V] gate, which includes the transitions and a part of the vowel formats, 100% for Bulgarian and at least 95% for Russian. Furthermore, at the Recognition gate, when the all of the vowel cues have been added to the "perception chain', participants from both groups recognize a word as having a plain or palatalized consonant word-initially with a precision of 100%.

Not only can subjects from both groups choose the correct consonant, but the level of confidence in their responses is at least –0.4 on the standardized ranking scale which means that they are 'fairly sure' of their choices. As the boxplots in Figures 3.6. a – d show, for the plain [v], [s], and [z], subjects' level of confidence rises noticeably at the Isolation Gate, or the first [V] gate. Following the first [V] gate, confidence ratings are even further improved but remain the same, through to the last [V] gate, the Recognition Gate.

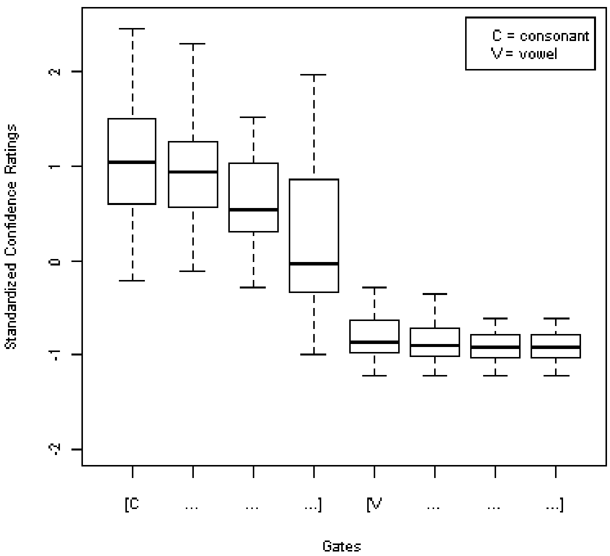


Figure 3.6.a. Boxplots of Confidence Rankings of all gates of Bulgarian [val], Audio Condition.

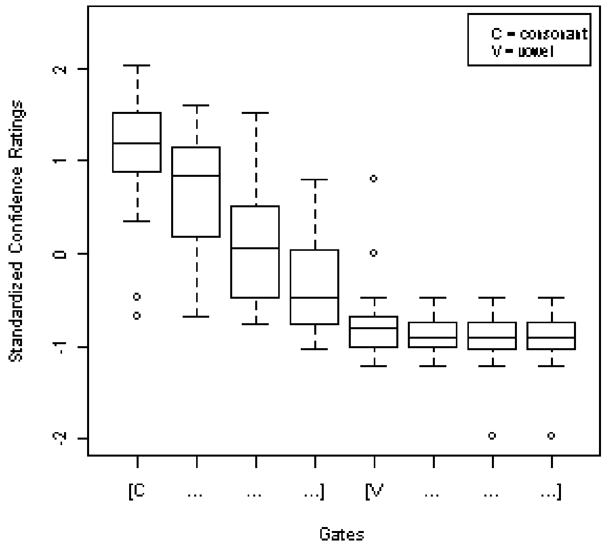


Figure 3.6.b. Boxplots of Confidence Rankings of all gates of Russian [val], Audio Condition.

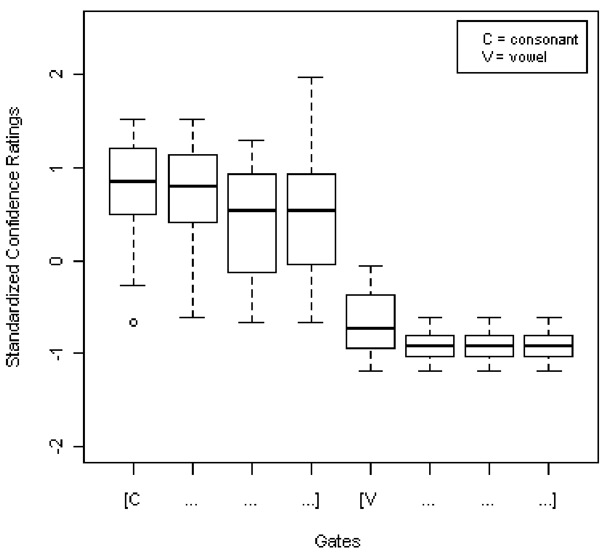


Figure 3.6.c. Boxplots of Confidence Rankings of all gates of Bulgarian [sal], Audio Condition.

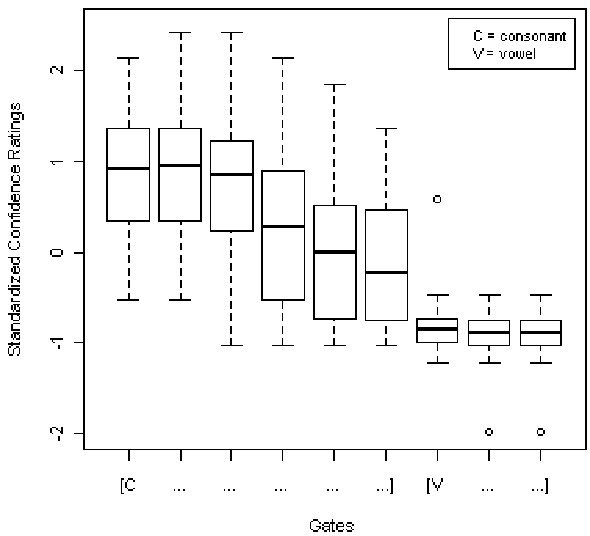
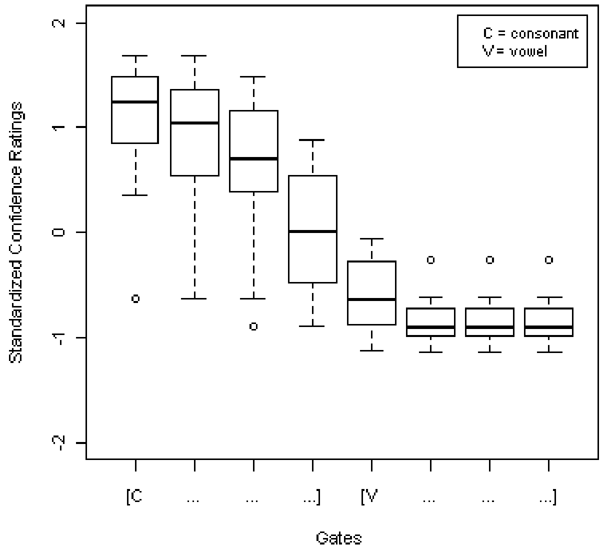


Figure 3.6.c. Boxplots of Confidence Rankings of all gates of Russian [sad], Audio Condition.



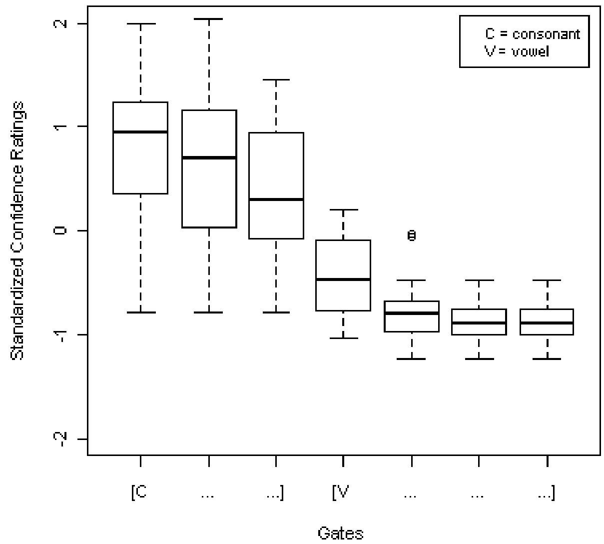
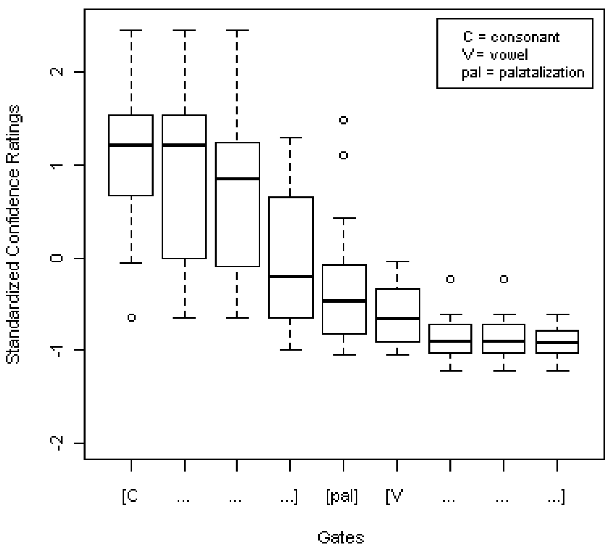


Figure 3.6.e. Boxplots of Confidence Rankings of all gates of Bulgarian [zapad], Audio Condition.

Figure 3.6.f. Boxplots of Confidence Rankings of all gates of Russian [zapad], Audio Condition.

Subjects' increase in confidence level at the Isolation Gate for the palatalized consonants is also evident in the boxplots of Figures 3.7.a – f. For most Russian and Bulgarian consonants (/[s^j z^j]), there is barely any increase in confidence ratings beyond the Isolation Gate. For Bulgarian subjects, the palatalization cues are spread over two gates.



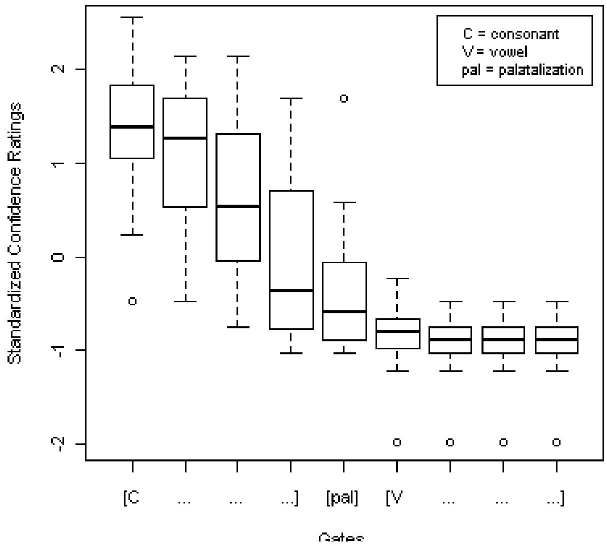


Figure 3.7.a. Boxplots of Confidence Rankings of all gates of Bulgarian [v^{j}al], Audio Condition.

Figure 3.7.b. Boxplots of Confidence Rankings of all gates of Russian [v^{j}al], Audio Condition.

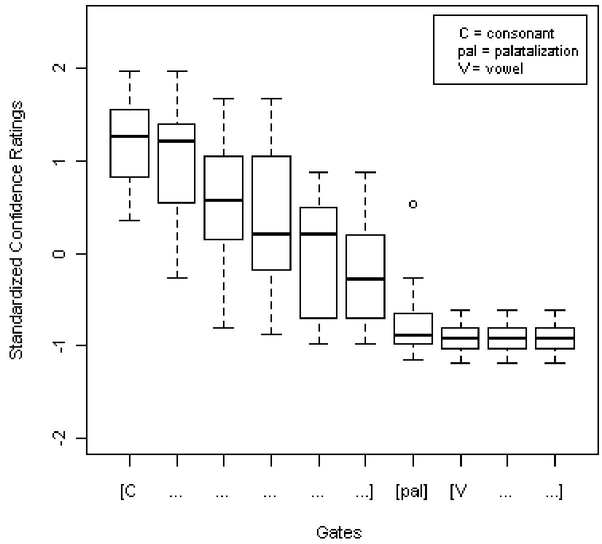


Figure 3.7.c. Boxplots of Confidence Rankings of all gates of Bulgarian [s^{j}al], Audio Condition.

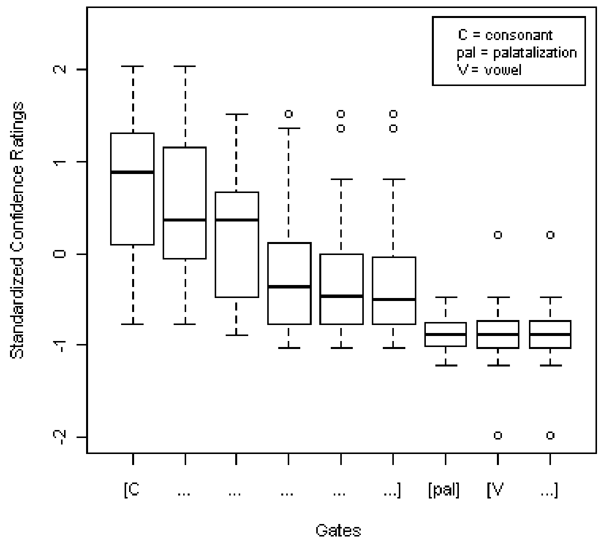


Figure 3.7.d. Boxplots of Confidence Rankings of all gates of Russian [s^{j}ad], Audio Condition.

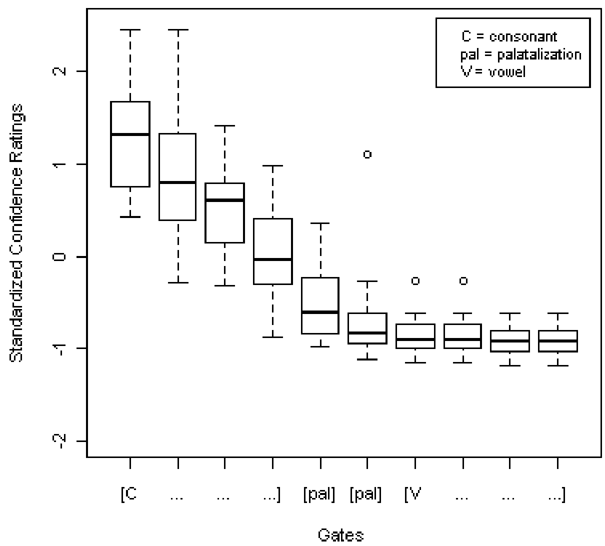


Figure 3.7.e. Boxplots of Confidence Rankings of all gates of Bulgarian [z^{j}apat], Audio Condition.

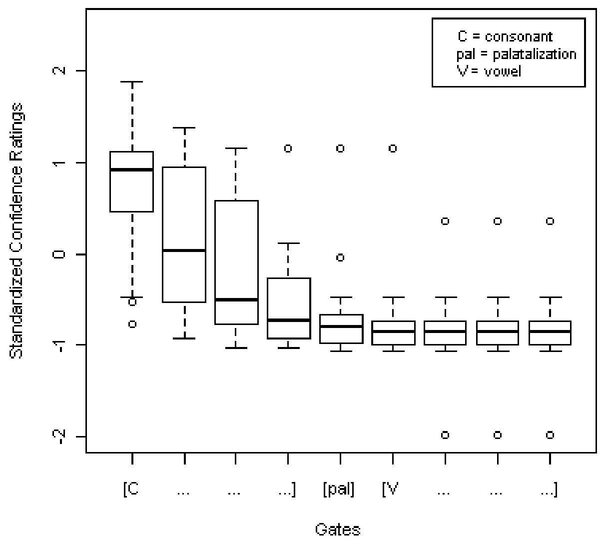


Figure 3.7.f. Boxplots of Confidence Rankings of all gates of Russian [z^{j}ab^{j}], Audio Condition.

Mean, range and standard deviation of confidence ratings of Bulgarian subjects for the plain and palatalized fricative consonants are shown in Table 3.9. below. Mean confidence ratings mirror the increase of confidence at the Isolation and Recognition Gate depicted by the boxplots.

Table 3.9. Confidence Ratings (in z-scores) for Fricative Consonants, [a] Context, Audio Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/v/	20	1.09	2.68	0.71	- 0.80	0.92	0.26	- 0.91	0.60	0.18
/v^j/	20	1.08	3.11	0.72	- 0.32	2.54	0.68	- 0.91	0.60	0.18
/s/	20	0.77	2.19	0.57	- 0.67	1.13	0.34	- 0.90	0.58	0.17
/s^j/	20	1.21	1.62	0.43	- 0.76	1.68	0.38	- 0.90	0.58	0.17
/z/	20	1.09	2.31	0.56	- 0.58	1.06	0.33	- 0.86	0.88	0.21
/z^j/	20	1.29	2.03	0.56	- 0.50	1.33	0.37	- 0.90	0.58	0.17
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/z^j/	20				- 0.67	2.22	0.48			

For each consonant, a separate Repeated Measures ANOVA (Table 3.10) with a factor 'Gate' was conducted to test for statistical significance in confidence levels across the critical gates. The Initial Gate serves as a point of reference in order to assess changes in the perception of these consonants as more perceptual cues become available at important subsequent gates. As before, the sphericity assumption was tested by the Mauchly test. In cases where it was violated, that is when the p-value of the Mauchly test was smaller than 0.05, the 'Greenhouse-Geisser Correction for Departure from Sphericity' was applied. The corrected p-values remained the same. As the Table 3.10. shows, there is a significant effect of Gate for all the consonants. To establish which gates carry significant importance in the identification of these consonants, pairwise t-tests were performed.

Table 3.10. Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [a] Context, Audio Condition, Bulgarian subjects.

Factor	**df**	**F**	**Pr(>F)**	**Sphericity Test**	**Pr(>F[GG])**
/v/ Gates	2, 38	174	< 0.001 ***	p = 7e-04	NA
/v^j/ Gates	2, 38	66	< 0.001 ***	p = 0.475	< 0.001 ***
/s/ Gates	2, 38	112	< 0.001 ***	p = 0.035	NA
/s^j/ Gates	2, 38	376	< 0.001 ***	p = 0.874	< 0.001 ***
/z/ Gates	2, 38	155	< 0.001 ***	p = 0.059	< 0.001 ***
/z^j/ Gates	3, 57	164	< 0.001 ***	p = 0.038	NA

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

For all plain consonants, subjects' dramatic increase in confidence at the Isolation and Recognition Gates is statistically significant:

- [v] - $F(2,38) = 174$, Initial vs. Isolation, $p < 0.001$; Initial vs. Recognition, $p < 0.001$;
- [s] - $F(2,38) = 112$, Initial vs. Isolation, $p < 0.001$; Initial vs. Recognition, $p < 0.001$;
- [z] - $F(2,38) = 155$, Initial vs. Isolation, $p < 0.001$; Initial vs. Recognition, $p < 0.001$;

The mean difference in the confidence of identifying a consonant as plain at the Identification Gate and Recognition Gate is statistically significant for [z] (Isolation vs. Recognition, $F(2,38) = 155$, $p = 0.32$), but not for [v] (Isolation vs. Recognition, $F(2,38) = 174$, $p = 0.42$) and [s] (Isolation vs. Recognition, $F(2,38) = 112$, $p = 0.66$). In terms of the palatalized consonants, the increases in confidence as subjects move from the Initial Gate and proceed to the Isolation and Recognition Gate is also statistically significant ($p < 0.001$), as for the plain confidence above. For [v^j], subjects are more confident at the Recognition Gate (Isolation vs. Recognition, $F(2,38) = 66$, $p = 0.002$). However, their confidence level did not increase at the Recognition Gates for [s^j] ($F(2,38) = 376$, $p = 0.19$) and [z^j] ($F(2,38) = 164$, $p = 0.167$). It is interesting that Bulgarian listeners did not feel more confident after the second [pal] gate, of [z^j] (Isolation (1) vs. Isolation (2), $F(2,38) = 164$, $p = 0.021$).

Mean, range and standard deviation of confidence ratings of Russian subjects for the plain and palatalized fricative consonants are shown in Table 3.11.

Table 3.11. Confidence Ratings (in z-scores) for Fricative Consonants, [a] Context, Audio Condition, Russian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/v/	22	1.03	2.71	0.74	- 0.73	2.03	0.43	- 0.90	1.51	0.31
/v^j/	22	1.36	3.04	0.67	- 0.39	2.74	0.66	- 0.90	1.51	0.31
/s/	22	0.86	2.67	0.72	- 0.78	1.80	0.36	- 0.90	1.51	0.31
/s^j/	22	0.71	2.80	0.78	- 0.85	1.76	0.20	- 0.85	2.18	0.39
/z/	22	0.83	2.77	0.73	- 0.46	1.23	0.36	- 0.85	0.76	0.20
/z^j/	22	0.73	2.65	0.65	- 0.70	2.22	0.48	- 0.82	2.34	0.40

Repeated Measures ANOVA, assuming sphericity, was performed to see if the mean confidence ranking differences across the critical gates was statistically significant. A Main effect of ‘Gate’ was found across consonants (Table 3.12.).

Table 3.12. Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [a] Context, Audio Condition, Russian subjects.

Factor	**df**	**F**	**Pr(>F)**	**Sphericity Test**	**Pr(>F[GG])**
/v/ Gates	2, 42	81	< 0.001 ***	p = 0.003	NA
/v^j/ Gates	2, 42	99	< 0.001 ***	p = 0.461	< 0.001 ***
/s/ Gates	2, 42	82	< 0.001 ***	p = 0.001	NA
/s^j/ Gates	2, 42	54	< 0.001 ***	p = 9.0595e-08	NA
/z/ Gates	2, 42	81	< 0.001 ***	p = 0.039	NA
/z^j/ Gates	2, 42	64	< 0.001 ***	p = 0.007	NA

‘R’ Significance Codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Post-hoc comparisons were conducted to establish at which gates subjects’ level of confidence was most increased. As with the Bulgarian plain and palatalized consonants, a dramatic increase in confidence between Initial and Isolation, and Initial and Recognition gates was found statistically significant ($p < 0.001$). Most notably, for the majority of the consonants, the mean difference in confidence rates between the Isolation and Recognition Gates was insignificant:

- [v] - $F(2,42) = 81$, $p = 0.3$;
- [s] - $F(2,42) = 82$, $p = 0.44$;
- [s^j] - $F(2,42) = 54$, $p = 1$;

- [z^j] - F(2,42) = 64, p = 0.43;

Only the consonants /z/ and /v^j/ were perceived more confidently as plain and palatalized, respectively, at the Recognition, compared to the Isolation Gate ([z], F(2,42) = 81, p = 0.008; [v^j], F(2,42) = 99, p = 0.005).

3. 5.1.5 Fricative Consonants [s s^j] in the Context of the Vowel /u/.

The sequences [su] and [s^ju] were identified with an accuracy of at least 90% at the Isolation Gate for both language groups. At subsequent gates, including the Recognition Gate, subjects' precision increased to 100%. Their correct responses at the Isolation and Recognition Gates are matched by their level of confidence, as shown by the boxplots in Figures 3.8.a – d.

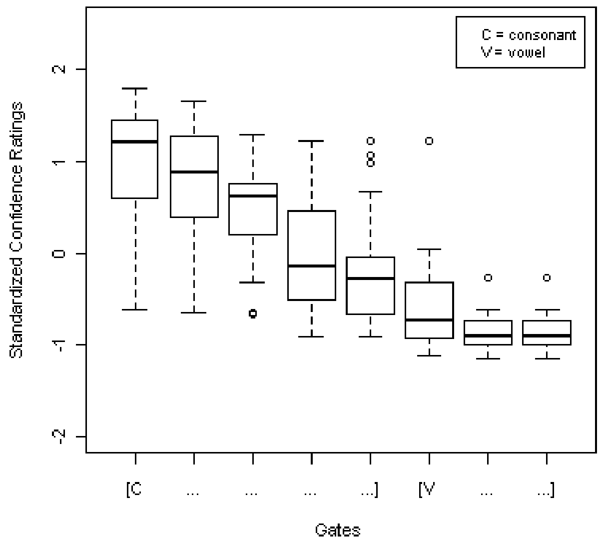


Figure 3.8.a. Boxplots of Confidence Rankings of all gates of Bulgarian [supa], Audio Condition.

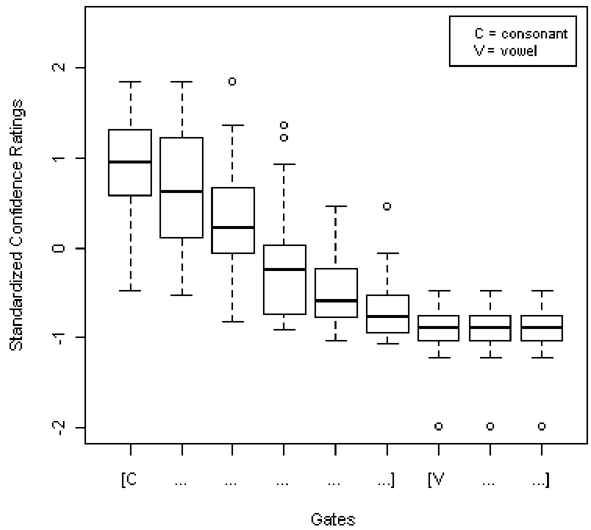


Figure 3.8.b. Boxplots of Confidence Rankings of all gates of Russian [sup], Audio Condition

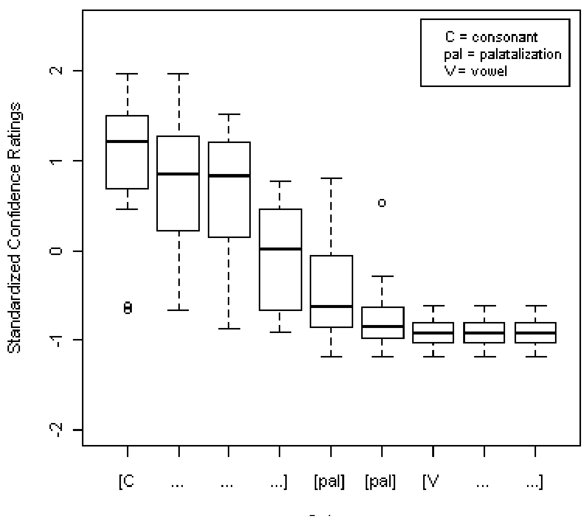


Figure 3.8.a. Boxplots of Confidence Rankings of all gates of Bulgarian [sʲu], Audio Condition.

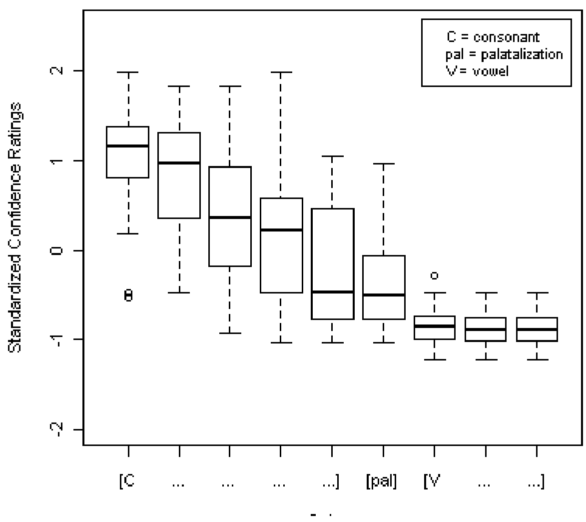


Figure 3.8.b. Boxplots of Confidence Rankings of all gates of Russian [sʲu], Audio Condition

Table 3.13. and Table 3.14. below present the averages, ranges and standard deviations of the confidence ratings of the two groups over the critical gates.

Table 3.13. Confidence Ratings (in z-scores) for Fricative Consonants, [u] Context, Audio Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/s/	20	0.99	2.41	0.62	- 0.58	2.34	0.54	- 0.86	0.88	0.21
/sʲ/	20	1.03	2.64	0.72	- 0.43	2.01	0.59	- 0.90	0.58	0.17
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/zʲ/	20				- 0.75	1.73	0.38			

Table 3.14. Confidence Ratings (in z-scores) for Fricative Consonants, [u] Context, Audio Condition, Russian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/s/	22	0.94	2.32	0.56	- 0.90	1.51	0.31	- 0.90	1.51	0.31
/sʲ/	22	0.96	2.52	0.70	- 0.42	1.99	0.52	- 0.85	0.76	0.20

Separate One-Way Repeated Measures ANOVA (assuming sphericity) was conducted for each consonant of both languages. In all cases, there was a main effect of Gate, Table

3.15 and Table 3.16. below. The most notable result of the post-hoc analyses was that there was no significant increase in confidence level between the Isolation and Recognition Gates of all of the consonants:

- Bulgarian: [s], F(2,38) = 112, p = 0.078; [s^j], F(3,57) = 63 , p = 359
- Russian: [s], F(2,42) = 144, p = 1; [s^j], F(2,38) = 63, p = 0.8

Even though there are two [pal] gates in the case of the Bulgarian [s^j] (F(2,38) = 63), the pairwise t-test indicated that subjects confidence level did not increase at the second gate (Isolation (1) vs. Isolation (2), p = 0.09).

Table 3.15. Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [u] Context, Audio Condition, Bulgarian subjects

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/s/ Gates	2, 38	112	< 0.001 ***	p = 0.249	< 0.001 ***
/s^j/ Gates	3, 57	63	< 0.001 ***	p = 0.003	NA

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 3.16. Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [u] Context, Audio Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/s/ Gates	2, 42	144	< 0.001 ***	p = 0.001	NA
/s^j/ Gates	2, 42	63	< 0.001 ***	p = 6.3074e-09	NA

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

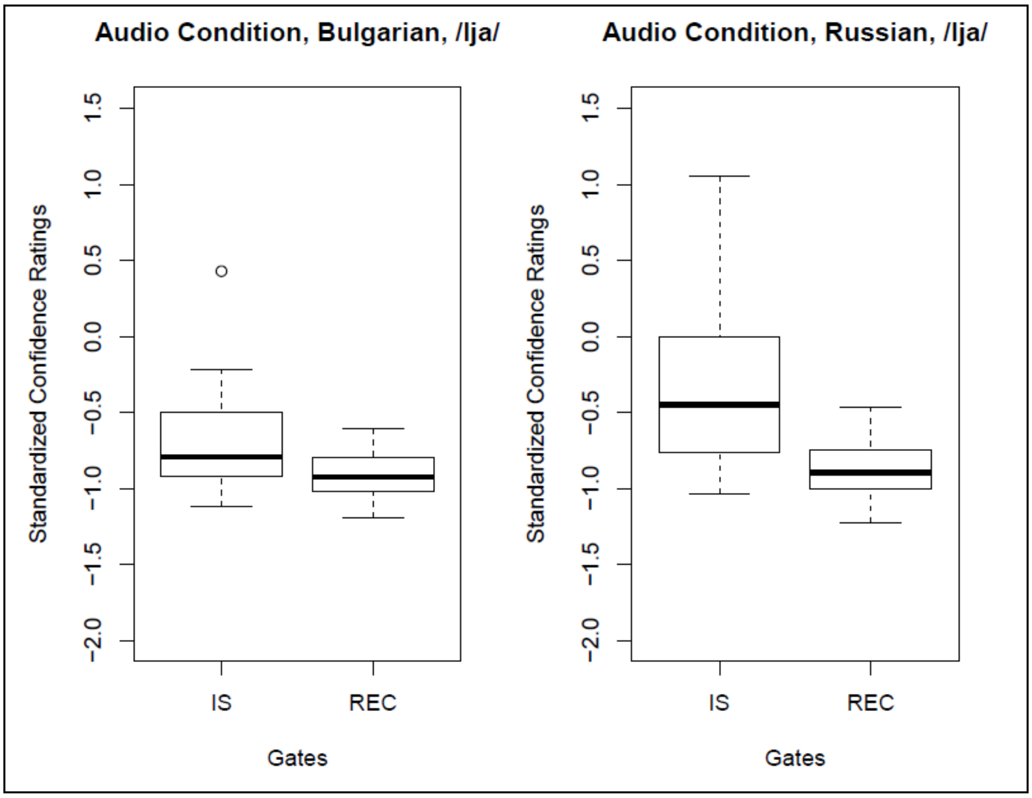
3.5.1.6 Summary of Results for Fricative Consonants [v s z v^j s^j z^j] in the Context of the Vowels [a] and [u].

Overall, the results indicate that the vowel context has no influence on the recognition of the investigated consonants, plain and palatalized. The results are identical to those of the plosive consonants. As soon as the palatalization cues ([pal] gate) are available to the subjects, they identify a consonant as palatalized. Importantly, when two [pal] gates are available, Bulgarian subjects are just as confident at the first [pal] in selecting the correct response. This was the situation with the [z^ja] and [s^ju] sequences.

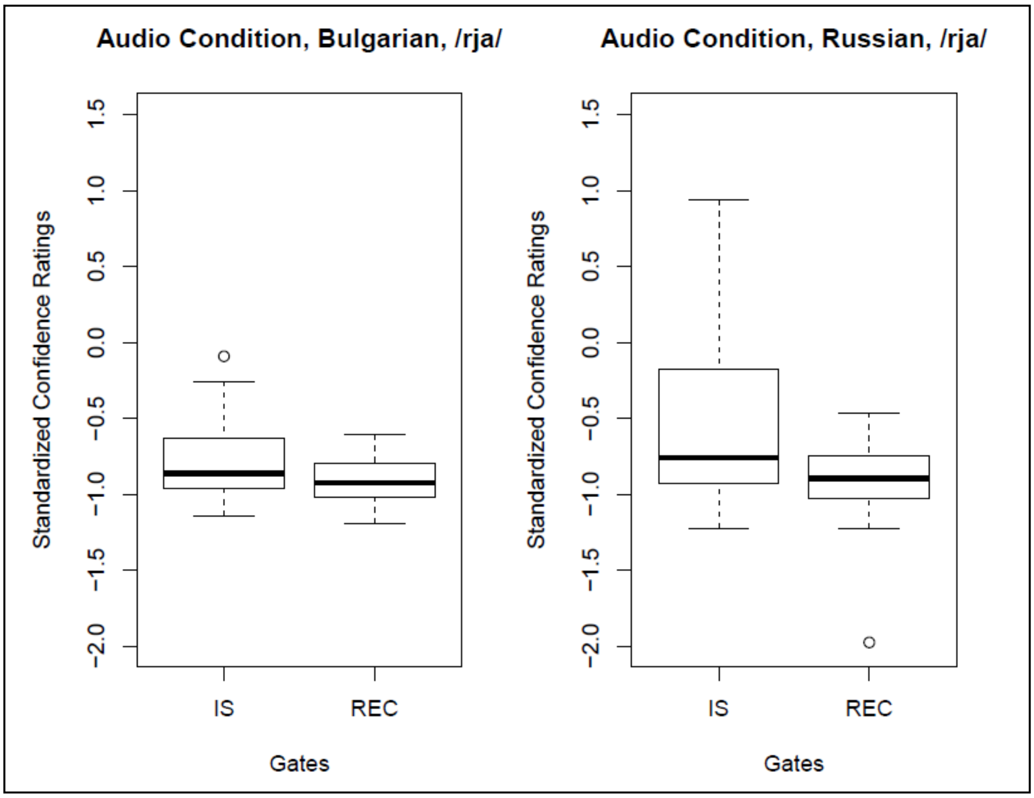
Moreover, the accuracy with which they identify these consonants as palatalized at the first [pal] gate is impressive; 100% for [z^j] and 95% for [s^j]. Bulgarian subjects do not need the transitions with the following vowel to identify a consonant as palatalized.

3.5.1.7 Approximants [l^j r^j n^j] in the Context of the Vowel [a]

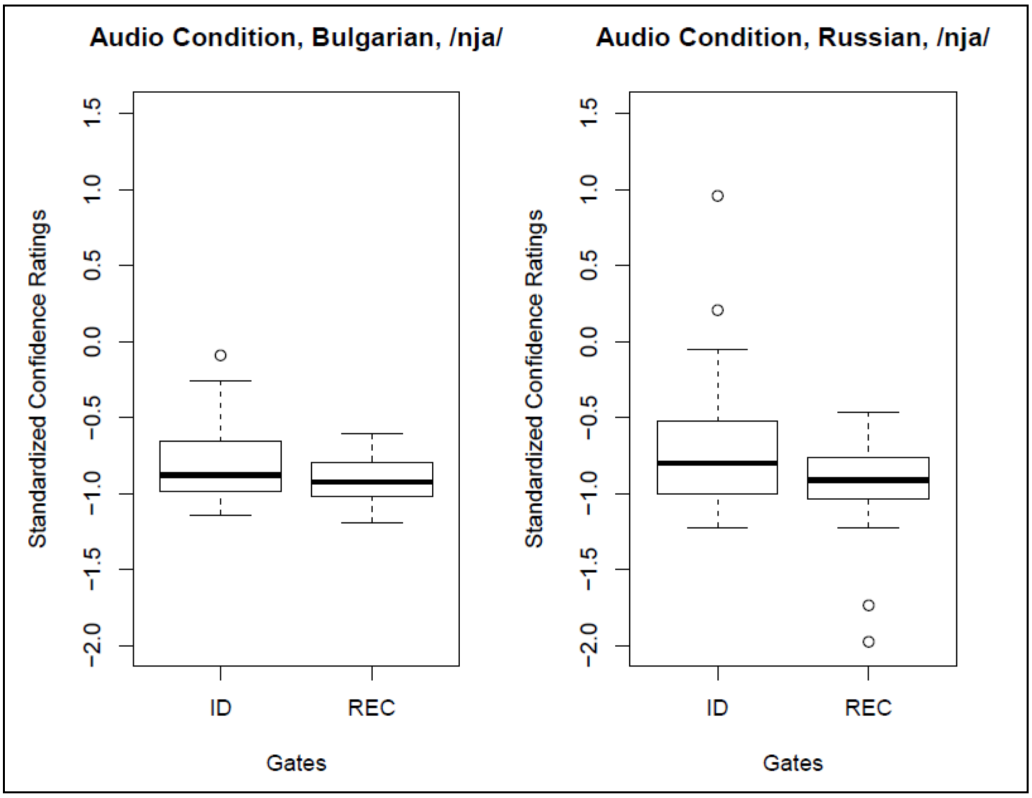
So far, our comparison of Bulgarian and Russian plain and palatalized consonants has revealed identical results. The boxplots have shown a consistent pattern. There is a sudden increase of confidence at the Isolation Gate. Over the subsequent gates, including the Recognition Gate, this level of confidence is maintained. Therefore, we will only compare these gates for both language groups. The reader is invited to look at the boxplots of the entire range of gates for these consonants in Appendix 4, page 00. Figures 3.9.a – d represent of the Isolation (IS) and Recognition Gates (REC) of the palatalized consonants /l^j r^j n^j/. It is immediately obvious that at the Isolation gate ([pal]) Bulgarian and Russian subjects are 'fairly sure' in the choice of their response. Moreover, they achieve an accuracy of at least 95%. At the Recognition Gate, their performance is flawless, 100%, and their confidence level is increased, 'very sure'.



. Figures 3.9.a Cross-Language Comparison of palatalized [l^j]



Figures 3.9.b. Cross-Language Comparison of palatalized [r^j].



Figures 3.9.c. Cross-Language Comparison of palatalized [n^j].

Table 3.17 and 3.18 give the averages, ranges and standard deviation for the two groups over the critical gates.

Table 3.17. Confidence Ratings (in z-scores) for Palatalized Approximants, [a] Context, Audio Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l^j/	20	0.24	2.43	0.75	- 0.67	1.55	0.37	- 0.90	0.58	0.17
/r^j/	20	0.96	2.64	0.74	- 0.49	1.83	0.54	- 0.90	0.58	0.17
/n^j/	20	0.91	2.89	0.73	- 0.45	1.99	0.51	- 0.81	0.58	0.27

Table 3.18. Confidence Ratings (in z-scores) for Palatalized Approximants, [a] Context, Audio Condition, Russian Subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l^j/	22	0.45	2.88	0.89	- 0.34	2.09	0.58	- 0.85	0.76	0.20
/r^j/	22	0.74	3.40	0.82	- 0.58	2.16	0.51	- 0.90	1.51	0.31
/n^j/	22	0.82	1.99	0.55	- 0.68	2.18	0.50	- 0.94	1.51	0.36

Separate Repeated Measures ANOVAs were performed for each and consonant and for each language. As the results in Table 4.19 and 4.20 indicate, the critical gates turned out to be a significant factor.

Table 3.19. Repeated Measures ANOVA of Confidence Ratings for Palatalized Approximants, [a] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/lʲ/ Gates	2, 38	32	< 0.001 ***	p = 0.012	< 0.001 ***
/rʲ/ Gates	2, 38	61	< 0.001 ***	p = 3.8367e-05	NA
/nʲ/ Gates	2, 38	64	< 0.001 ***	p = 0.0006	NA
'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

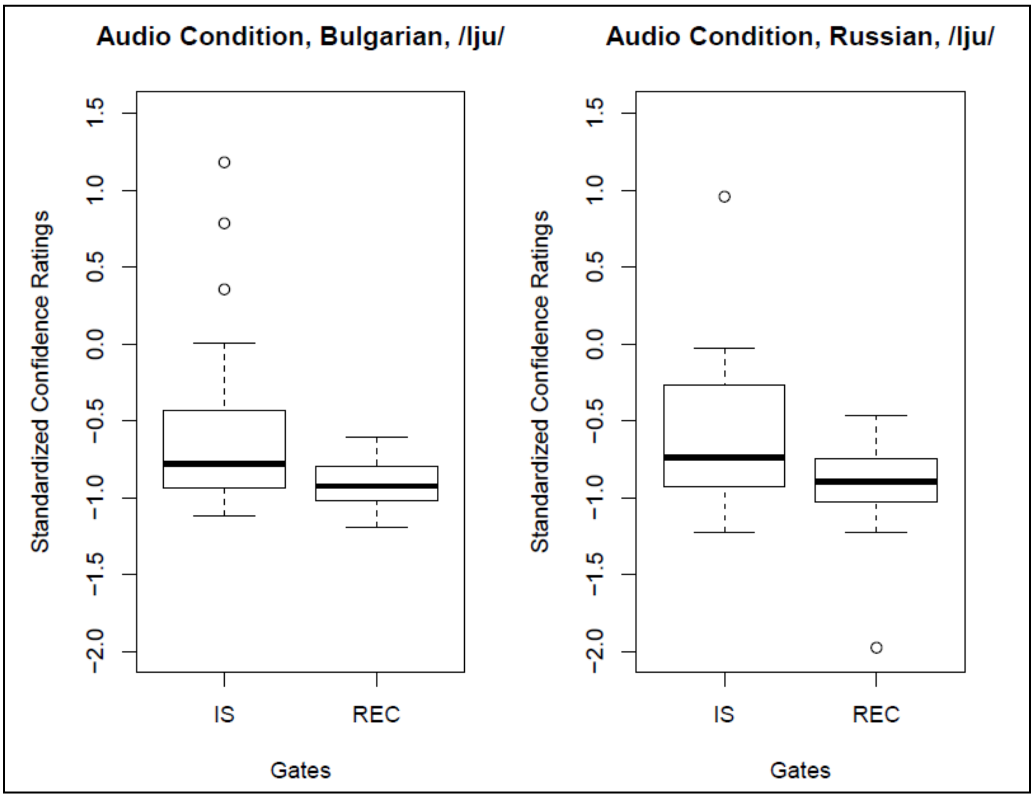
Table 3.20. Repeated Measures ANOVA of Confidence Ratings for Palatalized Approximants, [a] Context, Audio Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/lʲ/ Gates	2, 42	30	< 0.001 ***	p = 0.086	< 0.001 ***
/rʲ/ Gates	2, 42	51	< 0.001 ***	p = 1.7565e-06	NA
/nʲ/ Gates	2, 42	89	< 0.001 ***	p = 175	< 0.001 ***
'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

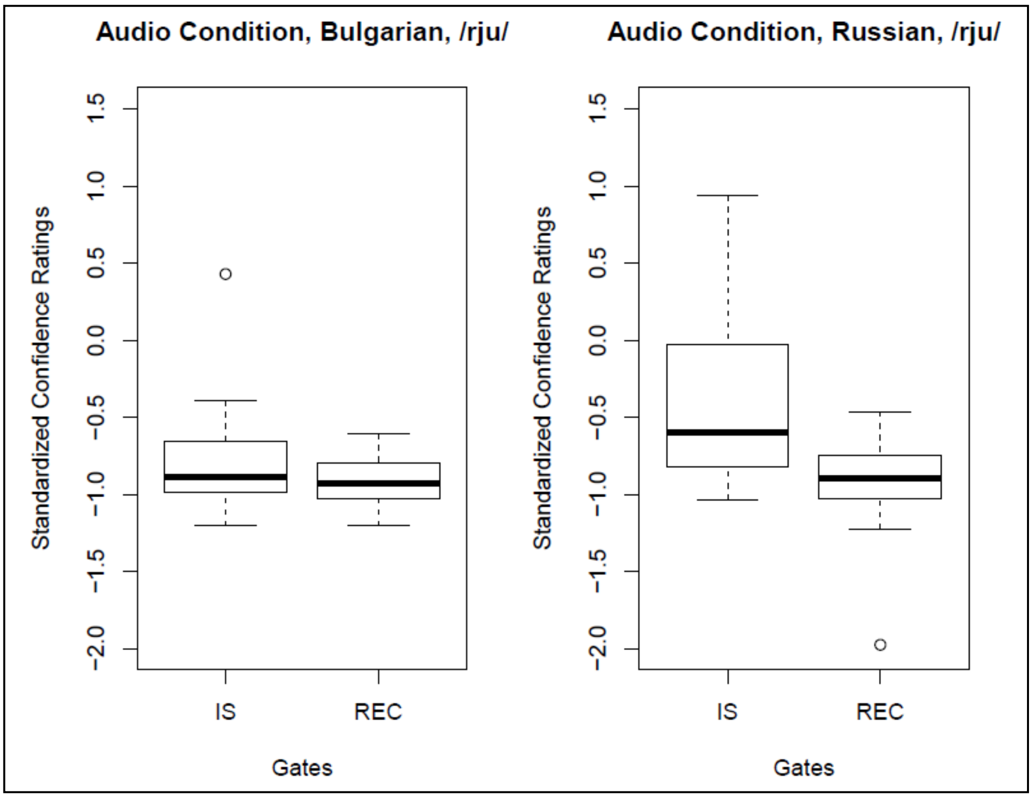
To determine if the mean differences in confidence levels between the critical gates were statistically significant, pairwise comparisons were conducted. Even though subjects' responses are highly accurate at the Identification Gate, for some of the consonants Bulgarian ([nʲ], $F(2,38) = 64$, $p = 0.01$) and Russian ([lʲ], $F(2,42) = 30$, $p = 0.007$) listeners are more confident at the Recognition Gate. The mean difference in confidence ranking in not significantly better at the Recognition Gate for Bulgarian [lʲ] ($F(2,38) = 32$, $p = 0.14$) and [rʲ] ($F(2,38) = 61$, $p = 0.029$), and Russian [nʲ]($F(2,42) = 89$, $p = 0.075$) and [rʲ] ($F(2,42) = 51$, $p = 0.14$).

3.5.1.8 Approximants [l^j r^j n^j] in the Context of the Vowel [u].

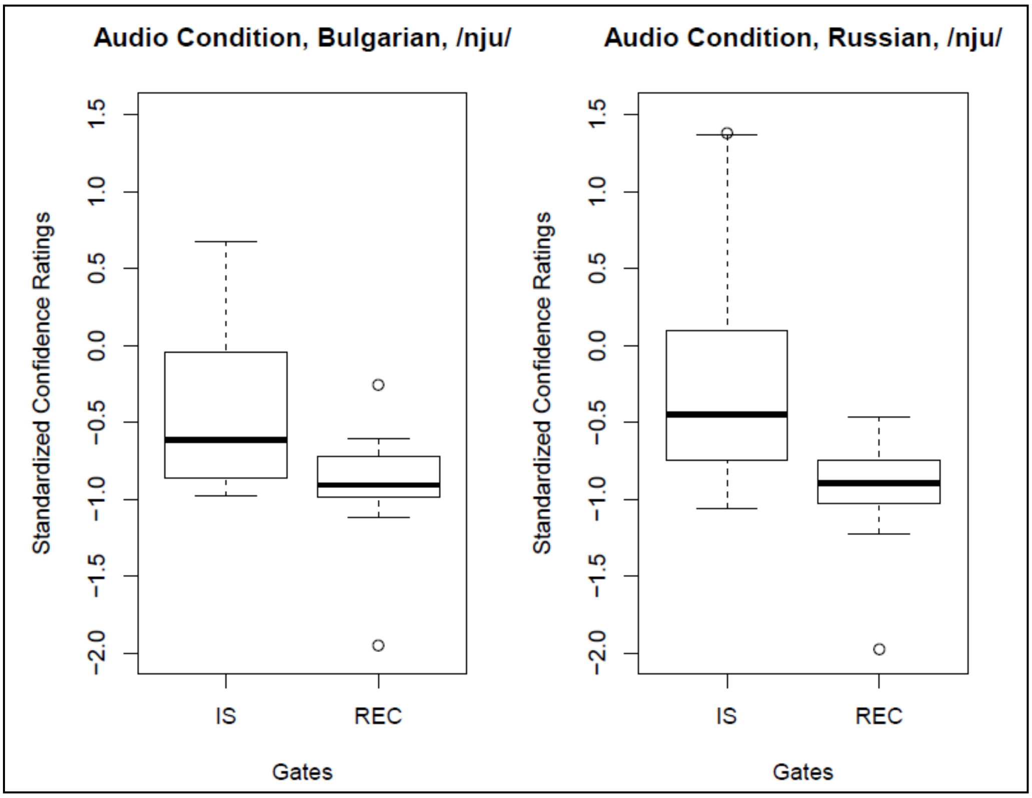
Figures 3.10.a – c represent a cross-language comparisons of the boxplots of Identification and Recognition Gates of the palatalized consonants [l^j r^j n^j], word-initially, before the vowel [u]. It is clear that at the Identification Gate the subjects from both language groups fairly confident in their recognition of a consonant as palatalized. Furthermore, they achieve an accuracy of at least 95%. At all subsequent gated, including the Recognition Gate, their performance is perfect – 100%. The reader is invited to observe confidence ranking of all consonants across all gates in Appendix 5, page 214.



. Figures 3.10.a. Cross-Language Comparison of palatalized [l^j].



. Figures 3.10.b. Cross-Language Comparison of palatalized [rʲ].



Figures 3.10.c. Cross-Language Comparison of palatalized [nʲ].

The means ranges, and standard deviations of the confidence rankings are shown in Table 3.21. and Table 3.22.

Table 3.22. Confidence Ratings (in z-scores) for Palatalized Approximants, [u] Context, Audio Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l^j/	20	1.07	2.58	0.59	- 0.49	2.30	0.64	- 0.90	0.58	0.17
/r^j/	20	1.19	2.96	0.64	- 0.80	1.63	0.35	- 0.91	0.59	0.18
/n^j/	20	0.99	2.58	0.67	- 0.38	0.55	1.66	- 0.86	0.88	0.21

Table 3.23. Confidence Ratings (in z-scores) for Palatalized Approximants, [u] Context, Audio Condition, Russian Subjects

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l^j/	22	0.11	2.10	0.67	- 0.49	3.04	0.70	- 0.90	1.51	0.31
/r^j/	22	0.83	3.24	0.90	- 0.41	1.97	0.54	- 0.90	1.51	0.31
/n^j/	22	1.05	3.05	0.84	- 0.22	2.44	0.71	- 0.90	1.51	0.31

One-Way Repeated Measures ANOVAs for each consonant, for both languages, established the 'Gate' factor to be significant, Table 3.24. and Table 3.25. Post-hoc comparisons between the Identification and Recognition Gates showed that subjects are more confident in their responses at the Recognition Gate, with the exception of Bulgarian [r^j]:

- Bulgarian [l^j], $F(2, 38) = 72$, $p = 0.014$
- Bulgarian [r^j], $F(2, 38) = 160$, $p = 0.42$
- Bulgarian [n^j], $F(2, 38) = 60$, $p = 0.01$
- Russian [l^j], $F(2, 42) = 18$, $p = 0.03$
- Russian [r^j], $F(2, 42) = 47$, $p = 0.0013$
- Russian [n^j], $F(2, 42) = 48$, $p = 0.013$

Table 3.24. Repeated Measures ANOVA of Confidence Ratings for Approximants, [u] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/lʲ/ Gates	2, 38	72	< 0.001 ***	p = 0.086	< 0.001 ***
/rʲ/ Gates	2, 38	160	< 0.001 ***	p = 0.009	NA
/nʲ/ Gates	2, 38	60	< 0.001 ***	p = 0.076	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 3.25. Repeated Measures ANOVA of Confidence Ratings for Approximants, [u] Context, Audio Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/lʲ/ Gates	2, 42	18	< 0.001 ***	p = 1.993e-06	NA
/rʲ/ Gates	2, 42	47	< 0.001 ***	p = 0.125	< 0.001 ***
/nʲ/ Gates	2, 42	48	< 0.001 ***	p = 0.638	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.5.1.9 Summary of Results for the Palatalized Approximants [lʲ rʲ nʲ] in the Context of the Vowels [a] and [u].

Bulgarian and Russian subjects do not need the transitions with the following vowel to identify the tested approximant consonants as palatalized, irrespective of vowel context. Moreover, at the Identification Gate, they achieve a very high accuracy of at least 95%. Also, they are quite confident in their choice of consonant at this point, although for some of the consonants this level of confidence rises at the Recognition gate.

3. 6 Discussion: Audio-Only Condition

The research on the perception of palatalized consonants of Standard Bulgarian is sparse. The previous research to test the perceptual cues associated with these consonants is that of Tilkov (1983). The main finding of his study was that Bulgarian perceivers needed the transitions with the following vowel to identify a consonant as palatalized. This conclusion was surprising in the light of Richie's (2000) more recent study on Russian palatalized consonant, according to which Russian subjects could identify a consonant as palatalized based on the information contained in the burst of plosive consonants.

Cross-language perception research is important as it gives us information on how perceptual processes may differ across languages. It is possible that Bulgarian and Russian palatalized consonants differ in their perceptual make-up. The current experiment was designed to tap into these issues by using the same methodology and stimuli that are matched in phonetic context. This is essential as there were methodological differences between the experiments of Tilkov and Richie. Also, it was impossible to assess if the discrepant result of Tilkov and Richie's studies were due to methodological issues as Tilkov's study is not described in detail. His article mentioned only the following information: (1) the stimuli consisted of minimal pairs, containing plain consonants and their palatalized counterparts; (2) the experimental stimuli were manipulated with the 'slice and splice' technique. It is therefore impossible to attempt to reproduce his study.

Nevertheless, the gating technique (Grosjean, 1980) was appropriate for the purpose of this study. As perceptual information unfolds progressively over successive gates, it is possible to assess how much of the stimulus is essential for the perception of palatalized consonants. The results of the current experiment indicate that, for both languages, subjects only need the information associated with the palatalization portion of the consonant to identify it as palatalized. That is, at the 'Isolation Gate', subjects can choose the word (from the presented minimal pair) which contains the palatalized consonant. Moreover, the accuracy of their responses is at least 95%. This result is consistent across all tested consonants, [t^j d^j l^j r^j n^j v^j s^j z^j]. Recall that these consonants were selected as in Stojkov's (1942, 1961) articulation studies there was very little difference in the articulation of these consonants and their plain counterparts.

The results from the current experiment diverge from those of Tilkov (1983). Bulgarian subjects do not need the transitions with the following vowel to perceive the consonants as palatalized. Furthermore, at the Recognition Gate, the point at which the entire range of vocalic perceptual cues were available, subjects' accuracy improved only by 5%, to reach 100%. The average confidence level was very high given that not the entire word was available for perception. In terms of the converted ranking scale in z-scores, subject's confidence level was around 1.0, compared to 1.2 on the converted (in z-scores) ranking scale. In other words, their rating of the confidence in their responses approached 'very sure'. Moreover, for many of the consonants, the mean confidence difference between the Isolation and Recognition Gates was not statistically significant. This means that, at least for those consonants, they did not need to hear any vocalic cues to determine if a consonant was palatalized. These results apply to the Russian participants as well.

The results from the audio-only condition of the perception experiment also indicate that Bulgarian palatalized consonants have not undergone depalatalization. That is, the secondary palatal glide /^{j}/ has not evolved into a primary palatal glide /j/. Recall that, in some instances, Bulgarian and Russian palatalized consonants contained two [pal] gates in succession. Recall also that, according to the Smoothing Spline ANOVA statistics of the acoustic study described in chapter 3, the British consonant – palatal glide sequences were maintained for longer duration. To take one example, the British English /nju/ contrast is maintained for an average duration of 0.15 seconds, while the both the Bulgarian and Russian /n^ju/ contrast is maintained for an average duration of 0.06 seconds., as indicated by the F2 formant contours of /nu/ and /nju/, or /n^ju/, sequences (Figure 2.51, page 81). If the secondary palatal glide /^{j}/ had evolved into a primary palatal glide /j/, a stimulus could potentially contain more than [pal] two gates.

Taken together, the results from the acoustic study and the audio-only condition provide a strong support for the existence of palatalized consonants in Standard Bulgarian.

Chapter 4

An Audio-Visual Perception Study of Bulgarian and Russian Palatalized Consonants: Audio-Visual Condition

4.1 Introduction

The last fifty years of research has shown that speech perception is inherently multimodal (Rosenblum, 2005), and so an audio-visual perception study of palatalized consonants was performed as well. A salient example of how the visual modality interacts with the auditory modality is the McGurk effect (McGurk & MacDonald, 1976). In a typical experiment eliciting the McGurk effect, a discrepant visual stimulus is dubbed onto an auditory stimulus. For example, subjects simultaneously see a face of a person articulating [ga] (visual percept) and hear a voice utterance of [ba] (auditory percept). They frequently report hearing a unified percept of [da]. Summerfield (1987) proposed a hypothesis, called VPAM (Visual: Place, Auditory: Manner), to explain the McGurk effect. In other words, the visual information cues the place of articulation and the auditory information cues the manner of articulation. Apart from the McGurk effect, research has also indicated that lip-reading can enhance the auditory input, especially when the content of the message is complicated (Reisberg, McLean, & Goldfield, 1987; Arnold & Hill, 2001). Furthermore, most people benefit from the visual modality when the auditory input is impoverished in the presence of background noise (Sumby & Polack, 1954; MacLeod & Summerfield, 1987).

The inclusion of the audio-visual condition was also motivated by insufficient research on audio-visual perception of secondary articulatory gestures. To the best of my knowledge, the only study investigating the audio-visual perception of secondary articulations in Rogers and Szakay's (2008) pilot study of Shona. The experiment was concerned with the perception of a secondary labial articulation on primary labial consonants. Subjects performed a discrimination task on minimal pairs, for example, [ama] vs. [amʷa]. There were two conditions, audio only and audio-visual. In the audio-visual condition, the acoustic signal was degraded, presumably with the addition of noise. The results indicated that Shona listeners were able to discriminate between labial segments with or without a secondary articulation, in both condition. Importantly, subjects could use visual cues to recognize secondary labial articulation when the auditory cues were degraded, despite a possible masking effect of rounding (Rogers & Szakay, 2008).

4.2 Hypotheses

Previous audio-visual studies have indicated that visual information can precede audio information. For instance, perceptual cues about vowel identity are available about 160 msec before the acoustic onset of the vowel (Cathiard, Lallouache, Mohamadi, & Abry, 1995). Observing the lips close is a sufficient cue of the labial place of articulation prior to the release of the consonant (Smeele, 1994), an event that signals a robust acoustic cue for place of articulation. On inspection of recorded video frames of palatalized consonants, it was observed that the lips assumed an 'i-like' spreading gesture prior to the consonantal release into the following vowel. Also, the shape of the lips during the articulation of both plain and palatalized consonants is influenced by the following vowel. That is, in the context of the vowel /u/, lip rounding begins before the articulation of the vowel, due to coarticulation. The shape of the lips remains fairly neutral in the context of the vowel /a/. Figures 5.1.a – d show the shape of the lips of the Bulgarian speaker prior to the release of the initial consonants in the words [tam], [tʲam],

[tula] and [t^jula], respectively. As mentioned before, lip spreading associated with the palatal gesture begins even prior to the release of the consonant.

Based on these observations, it was expected that in the audio-visual condition the Isolation points could shift to an earlier gate, compared to the audio condition. Recall that in the audio condition we established two types of Isolation Points: (1) for plain consonants, the gate which contained the first potion of the following vowel; (2) for palatalized consonants, the gate containing the acoustic information for palatalization. The Isolation Points in (1) and (2) we established on the grounds of the two dependent variables, the percentage of correct responses and conferences ratings at the respective gates. Furthermore, it was expected that at the Recognition Gate (the final gate, which contains the last portion of the vowel) subjects' confidence level would, at least, approach 1.4 ('very sure') on the standardized rating scale. As secondary articulatory gestures have not been extensively studied, it was difficult to set more specific hypotheses.

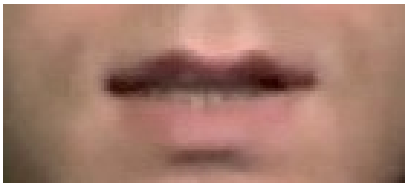


Figure 4.1.a [t] in Bulgarian [tam]

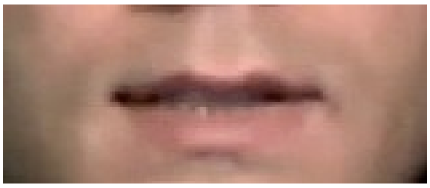


Figure 5.1.b [t^j] in Bulgarian [t^jam]

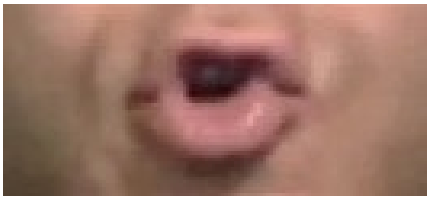


Figure 5.1.c [t] in Bulgarian [tula]

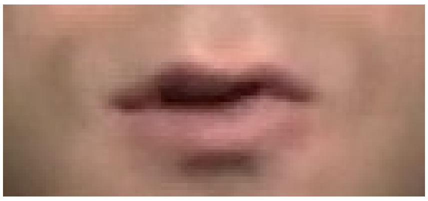


Figure 5.1.c [t^j] in Bulgarian [t^jula]

4.3 Results: Audio-Visual Condition.

4.3.1 Overview of the Results

The results from this part of the experiment will be presented separately for each language group. Kricos and Lesner (1982) have shown that readability of visual cues vary across talkers. As the Russian and Bulgarian audio-visual stimuli were produced by two different speakers, the result for the two languages will not be presented alongside one another, as in previous chapters.

In order to distinguish palatalized consonants from their plain counterparts, subjects should be able to notice, at the very least, the presence or absence of lip-spreading. Based on previous research (outlined in the introductory section), we would expect these visual cues to precede the auditory information. In other words, compared to the audio-only condition, visual cues in the audio-visual condition should shift the Isolation point to an earlier gate. This did not occur in the current study. It turned out that the gating procedure, as it was implemented in the current study, had some limitations. Unfortunately, at the early gates, the visual cues were degraded due to insufficient information. Subjects benefited from the visual cues in the later gates as the duration of the video clip increased. Consequently, the Isolation Point in the audio-visual condition coincided with that of the audio-only condition. Furthermore, consonants richer in perceptual cues better resisted the effects of the noise masker. This meant that, in addition to the visual cues, subjects had more auditory cues available. For this reason, the best results were obtained for the liquid consonants [l l^j r r^j]. On the opposite end of the performance scale, the worst results were obtained for the fricative consonants as the white noise masked their most important perceptual cues which are contained in the high frequency regions. Thus, in the case of fricatives, the audio-visual condition became comparable to the visual-only condition in other experiments. As we pointed out in the introduction section, recognition scores are poor when subjects have to identify a consonant based on visual information only. Unfortunately, it was impossible to predict these confounds when the methodology for the audio-visual condition was considered. All the confounds discovered in the current audio-visual experiment are very important and must be taken into consideration in future audio-visual research. It is hoped that the current study will make a contribution to research methods in audio-visual speech perception.

4.3.2 Discussion of the Results

As found by previous studies (Benguerel & Pichora-Fuller, 1982; Cathiard et. al, 1995, among others), coarticulatory dynamics allow vowels to modify the lip configuration involved in the articulation of preceding consonants. Not surprisingly, this principle also applies to the investigated word initial consonants of Standard Bulgarian and Russian. When a consonant in these languages is palatalized, the shape of the lips is not only influenced by the following vowel but also by the palatalization process. More specifically, the corner of the mouth spreads sideways in a manner similar to that of an '/i/-like' gesture. Figures 5.28 (b) and (d) show the shape of the lips during the articulation of the Bulgarian palatalized consonant [t^j] in the context of the vowels [a] and [u], respectively.

Although no specific information about individual consonants was reported[6], Massaro and associates (Smeele, 1999; De la Vaux & Massaro, 2004; Jesse & Massaro, 2010) found out that in their audio-visual conditions subjects' performance improved in the early gates as they benefited from the additional visual cues. The same effect was not found in the current study. It turned out that the gating procedure impaired the flow of

[6] This is not surprising in view of the fact that the gating task degrades the quality of the visual stimuli.

visual information in the early gates as the video clips were seen as a flicker. It was not until gate 5, or 6, that the duration of the audio-visual clip was sufficient to provide them with the necessary visual cues on palatalization, that is, the lip-spreading gesture. This happened to coincide with the Isolation Gate for the audio-only condition. Therefore, there was no shift to an earlier gate for the Isolation point (the point at which subjects correctly identify a consonant without any change in response thereafter. When the experiment was designed, it was not possible to predict that the short duration of the early gates would deprive subjects of sufficient visual information as audio-visual gating methodologies are not consistent in the duration of gates, or the use of noise.

In the audio-visual condition, the Russian group performed better than the Bulgarian group at perceiving the visual information. This may be due to differences in the intelligibility of the visual articulatory cues of the Russian and Bulgarian speakers who produced the stimuli. Krocos and Lesner (1982) found variations in the interpretability of the visual cues of their six talkers. In the study of Munhall and Tohkura (1996), there were differences in the McGurk effect elicited by the tokens of four different speakers. For both groups, generally the level of confidence was higher at the Isolation Gate. However, as the kernel density plots revealed, Bulgarian and Russian subjects were more confident in their responses at the Isolation Gate of the audio only condition, compared to those at the Isolation Gate of the audio-visual condition.

For the Russian group, the following pattern in the results emerged: The best overall performance was achieved for the liquid consonants, followed by the plosive consonants; performance accuracy decreased for the nasal consonants, while the worst results were obtained for the fricative consonants. At the Isolation Gate, the Russian group were very accurate in identifying the plain [l] and [r] and their palatalized counterparts [l^j] and [r^j] in both vowel contexts, with accuracy between 86% and 100%.

The tested Russian plosive consonants were identified quite well, except for the plain [t] in the context of [a] (55%). The Russian palatalized nasal consonants were recognized above chance (64% and 68%) in the both vowel environments. The performance for the plain [n] was uneven, 91% for [nu] and 64% for [na]. Among the fricative consonants, only the plain and palatalized [v^j] were identified accurately. The palatalized sibilants [s^j] and [z^j] were very poorly recognized, 27% and 36%.

The results were more mixed for the Bulgarian group. The best results were obtained for the plain [l] and palatalized [l^j] lateral consonants, between 90% and 100%, in both vowel contexts. The palatalized alveolar trill [r^j] was identified at 65% and 70% in the environment of [u] and [a], respectively. The palatalized nasal consonant [n^j] at 80% next to [a] and 65% next to [u]. Both the plain [t] and palatalized [t^j] were identified at chance level when preceding the vowel /a/. In the context of /u/, the Bulgarian palatalized [t^j] and [d^j] were indentified above chance (60% and 70%, respectively), but their plain counterparts were recognized at, or below, chance ([t] at 30%; [d] at 50%). Except for the plain [v] and [z] in the environment of [a], the rest of the tested Bulgarian fricative consonants were very poorly recognized.

On the grounds of the described results, it may be tempting to conclude that, in the audio-visual condition, Bulgarian and Russian speakers benefited from the visual cues of the liquid consonants only. However, such a conclusion may be premature. While the results indicate that the subjects from both group identified the liquid consonants most accurately, it is interesting that they achieved the worst performance for the fricative consonants, in particular the sibilants. Recall that the signal-to-noise ratio of the audio-visual stimuli was reduced by 10dB in order to encourage the participants to attend to the visual information. In effect, the white Gaussian noise masks the auditory cues. Liquid consonants are richer in acoustic cues so it is not surprising that the results of this study indicate that they were the most resistant to perceptual confusions. On the other hand, the sibilants appear to be least resistant to the masking qualities of the white noise, which obscures the perceptual cues contained in their high frequencies.

The question arises as to how the reduced auditory cues could interfere with the perception of visual information. It is well established that in experimental conditions in which only visual cues are made available, subjects perform very poorly in consonant identification. Moreover, recent studies (Ross et al, 2006; Ma et al., 2009) have challenged the findings of Sumby and Pollock (1954) that the benefit of visual information increases as the SNR decreases. Furthermore, in a classic experiment, Miller and Nicely (1954) found out that some features (e.g, nasality and voicing) are more resistant to noise than others (e.g., place of articulation). With regards to the current experiment, the consonants whose perceptual cues are less resilient to the masking of noise would appear not to benefit from the visual information. That is, as in their case the acoustic signal is highly impoverished, the audio-visual condition would be more like a visual only condition.

There is another important observation in the results of the current audio-visual study. It is often the case that, under the same noise conditions, the plain consonant could be identified more accurately than its palatalized counterpart, or vice versa. As these inconsistencies occur within each language, it is unlikely that they could be attributed to the intelligibility of visual cues of the Russian or Bulgarian speaker. Carhart et al. (1969) have pointed to the potentially distracting effect of the masker. More specifically, intelligibility may suffer if attentional resources are directed at processing the masker. Recent studies have shown that the strength of the McGurk effect decreases when demands on attention are increased (Alsius, Navarra, Campbell, & Soto-Faraco, 2005; Tiippana, Andersen, & Sams, 2006). It is plausible that, under more intense masking conditions, Bulgarian and Russian listeners are distracted by the masking noise and unable to perceive the available visual information. All these issues are worth investigating and we will come back to them again when we outline the directions for future research.

The results of the audio-visual experiment are presented separately for each language. It was already explained that they are confounded by the nature of the gating task and the type of noise used in the experiment. Nevertheless, the results are included for readers who are may be interested in looking at them.

4.3.3 Results: Bulgarian Subjects.

4.3.3.1 Plosive Consonants [t d t^j d^j] in the Context of the Vowel [a]

Among the four consonants, only [d] (100%) and [d^j] (45% at [pal1], 95% at [pal2]) were perceived accurately at the Isolation Gate. The other plosives, [t] and [t^j] were identified with an accuracy of 45% and 55%, respectively. At the Recognition Gate, all consonants were perceived accurately, 100%. The level of precision in identifying a consonant as plain or palatalized at the Isolation Gate is mirrored by the subjects' level of confidence. On average, they were 'fairly sure' in selecting [d] and [d^j] at the Isolation Gate. In terms of [t] and [t^j], this measure of confidence was reached at the second [V] gate. (Figures 4.2. a – d)

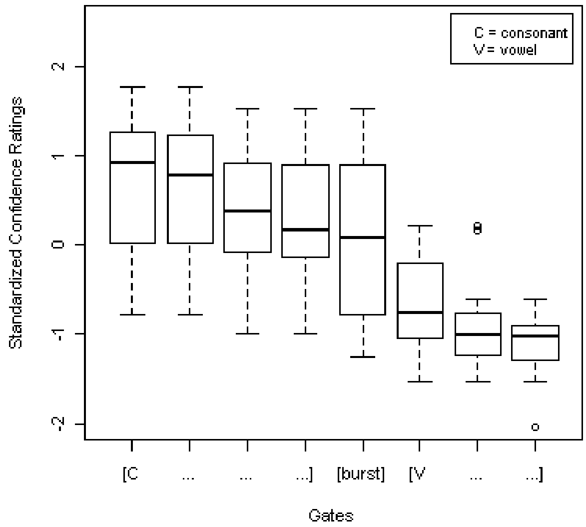


Figure 4.2.a. Boxplots of Confidence Rankings of all gates gates of Bulgarian [dava], Audio-Visual Condition.

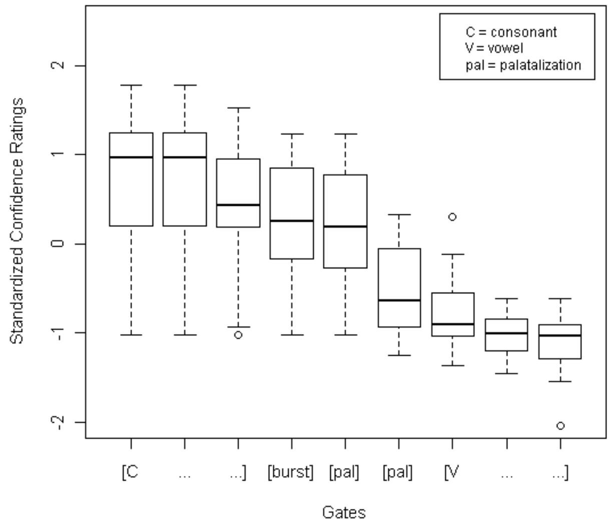


Figure 4.2.b. Boxplots of Confidence Rankings of all of Bulgarian [d^java], Audio-Visual Condition

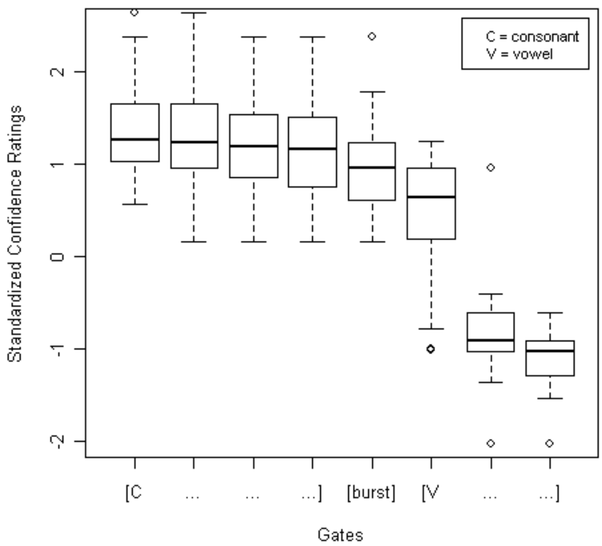


Figure 4.2.c. Boxplots of Confidence Rankings of all gates gates of Bulgarian [tam], Audio-Visual Condition.

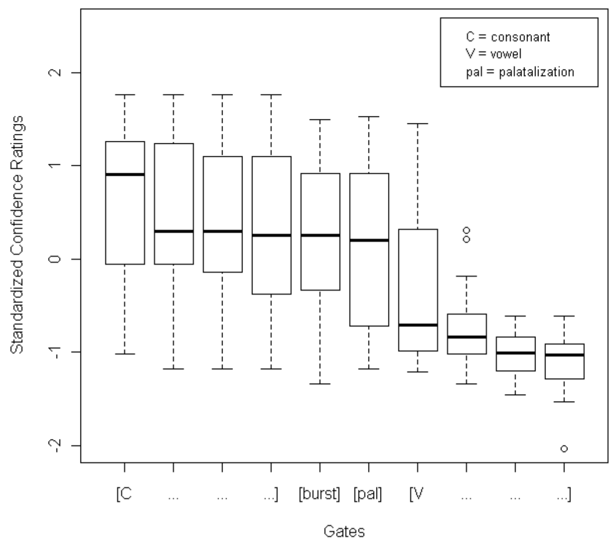


Figure 4.2.d. Boxplots of Confidence Rankings of all of Bulgarian [t^jam], Audio-Visual Condition

Table 4.1. shows that there is a difference in the average confidence rankings for the critical gates of all consonants. To find out if this difference is statistically significant, separate One-Way Repeated Measures ANOVAs were performed (Table 4.2). The ANOVA analyses indicated only a slight shift in confidence, from 'very unsure' to 'fairly unsure' between the Initial and Isolation Gates of [t] ($F(2,38) = 113$, $p < 0.001$) and [t^j]

(F(2,38) = 66, p = 0.035, approaches significance). The increase in confidence was greater between the Initial and Isolation Gates of /d/ and /d^j/, from 'very unsure' to 'fairly sure', [d] (F(2,38) = 54, p < 0.001) and [d^j] (F(3,57) = 49, p = 0.0052, Isolation (2)). For all consonants, the mean difference between the Isolation and Recognition Gates is statistically significant as the confidence level jumps up to 'very sure' [t] (F(2,38) = 113, p < 0.001), [t^j] (F(2,38) = 66, p < 0.001), [d] (F(2,38) = 54, p < 0.001), [d^j] (F(2,38) = 49, p < 0.001).

Table 4.1 Confidence Ratings (in z-scores) for Plosive Consonants, [a] Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			**Isolation Gate (1)**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/t/	20	1.41	2.08	0.52	0.46	2.27	0.70	- 1.11	1.42	0.33
/t^j/	20	0.65	2.78	0.82	0.14	2.70	0.93	- 1.11	1.42	0.33
/d/	20	0.71	2.55	0.76	- 0.70	1.75	0.53	- 1.11	1.42	0.33
/d^j/	20	0.72	2.80	0.79	0.17	2.25	0.67	- 1.11	1.42	0.33
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/d^j/	20				- 0.49	1.58	0.53			

Table 4.2 Repeated Measures ANOVA of Confidence Ratings for Plosive Consonants, [a] Context, Audio-Visual Condition, Bulgarian subjects.

Factor	**df**	**F**	**Pr(>F)**	**Sphericity Test**	**Pr(>F[GG])**
/t/ Gates	2, 38	113	< 0.001 ***	p = 0.038	NA
/t^j/ Gates	2, 38	66	< 0.001 ***	p = 0.008	NA
/d/ Gates	2, 38	54	< 0.001 ***	p = 0. 132	< 0.001 ***
/d^j/ Gates	3, 57	49	< 0.001 ***	p = 0. 229	< 0.001 ***
'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

4.3.3.2 Plosive Consonants [t d t^j d^j] in the Context of the Vowel [u].

The response accuracy for the plain consonants [t] and [d] in the environment of the vowel [u] was low, 30% and 50%, respectively. It was much better for [d^j] (70%) and just above chance for [t^j] (60%). Recall that subjects had only a partial gesture available at the [pal] gate for [t^j]. The confidence rankings across gates for all four consonants are represented in Figures 5.3. a – d. Subjects did not feel confident in identifying the plain /t/ and the palatalized [tʲ] until the last and the penultimate gates, respectively. The results are better for [d] and [dʲ] in that subjects' confidence level increased at the Identification Gates (first [V] for the plain consonant; [pal] for the palatalized consonant).

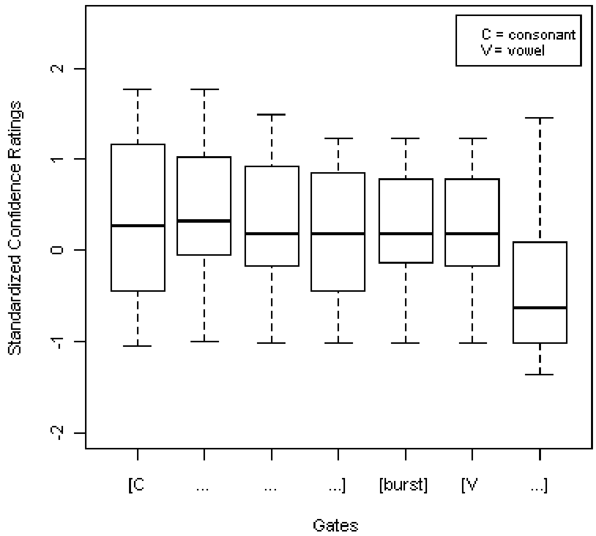


Figure 4.3.a. Boxplots of Confidence Rankings of all gates Bulgarian [tula], Audio-Visual Condition.

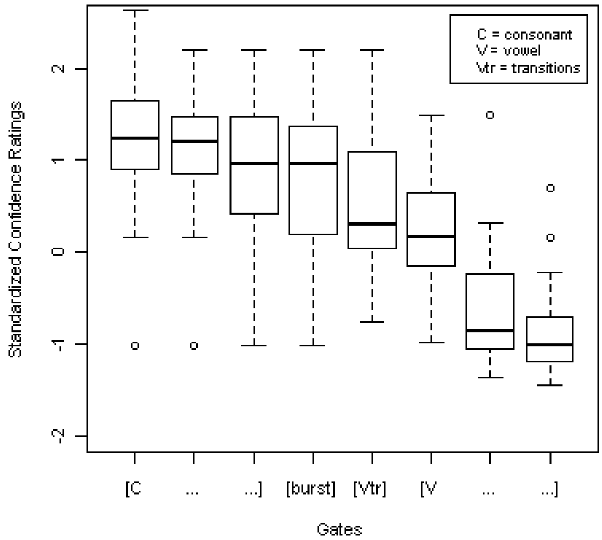


Figure 4.3.b. Boxplots of Confidence Rankings of of all gates of Bulgarian [tʲula], Audio-Visual Condition

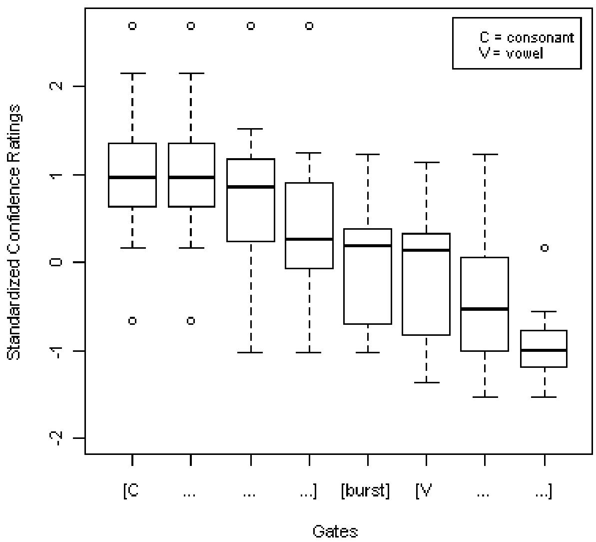


Figure 4.3.c. Boxplots of Confidence Rankings of all gates gates of Bulgarian [dunav], Audio-Visual Condition.

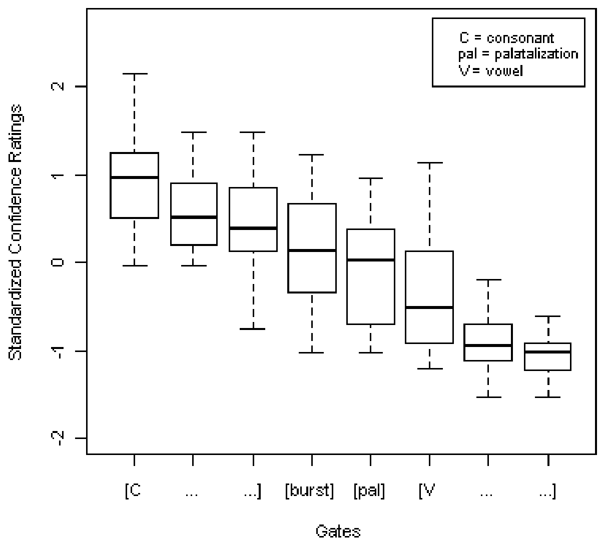


Figure 4.3.d. Boxplots of Confidence Rankings of all of Bulgarian [dʲuna], Audio-Visual Condition

Table 4.3 shows the mean, range and standard deviation of the rankings of confidence levels of the consonants. We can notice an increase in the average score at the Isolation Gates of [d] and [d^j], identical to the boxplots. This is not the case with [t] and [t^j]. Table 4.4 shows the results from the One-Way Repeated Measures ANOVAs, according to which there is a main effect of the Gate.

Table 4.3 Confidence Ratings (in z-scores) for Plosive Consonants, [u] Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			**Isolation Gate**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/d/	20	1.02	3.35	0.73	- 0.12	2.50	0.73	- 0.95	1.70	0.37
/d^j/	20	0.95	2.20	0.56	- 0.05	1.99	0.65	- 1.05	0.93	0.25
/t/	20	0.31	2.81	0.92	0.17	2.26	0.69	- 0.44	2.82	0.75
/t^j/	20	1.23	3.66	0.79	0.54	2.97	0.71	- 0.85	2.15	0.53
					Vowel transitions					
					Mean	**Range**	**SD**			
/t^j/	20				0.21	2.15	0.67			

Table 4.4 Repeated Measures ANOVA of Confidence Ratings for Plosive Consonants, [u] Context, Audio-Visual Condition, Bulgarian subjects.

Factor	**df**	**F**	**Pr(>F)**	**Sphericity Test**	**Pr(>F[GG])**
/t/ Gates	2, 38	5	0.009 **	p = 0.353	0.011 **
/t^j/ Gates	3, 57	36	< 0.001 ***	p = 0.246	< 0.001 ***
/d/ Gates	2, 38	43	< 0.001 ***	p = 0.197	< 0.001 ***
/d^j/ Gates	2, 38	40	< 0.001 ***	p = 0.168	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Post-hoc comparisons between the gates of [t] confirmed that subjects were not more confident at the Isolation Gate than the Initial Gate (F(2,38) = 5, p = 0.589). The mean confidence difference between the Isolation and Recognition Gates is significant (p = 0.012). With regards to [t^j], subjects were more confident in their responses at the Isolation Gate, compared to the Initial Gate (F(3,57) = 36, p = 0.0042). There is no change in their confidence between the Isolation Gate and the Vowel Transitions Gate ((F(3,57) = 36, p = 0.1319), though the mean difference in confidence between the

Vowel Transitions and Recognitions Gates is statistically significant ($p < 0.001$). Subjects were more confident in identifying [d] and [d^j]. There is a significant difference in confidence ranking between all of their pairs of critical gates, Initial, Isolation and Recognition ([d], $F(2,38) = 43$, $p < 0.001$; [d^j], $F(2,38) = 40$, $p < 0.001$).

4.3.3.3 Summary of Results – Plosive Consonants [t d t^j d^j] in the Context of the Vowels [a] and [u].

The results for these consonants do not seem to be influenced by the vowel context, though, it is interesting that both palatalized consonants are identified when they are followed by [u]. The voiced plain [d] and palatalized plosives [d^j] tend to be perceived better in both contexts. The voiceless plosives [t] and [t^j] were generally less confidently identified at the Isolation Gates in both vowel contexts. There was hardly any increase of confidence between the Initial and Isolation Gates. All consonants were correctly (90% - 100%) identified at the Recognition Gate. With the exception of /tu/ ('fairly sure'), subjects felt 'very sure' about their responses.

4.3.3.4. Fricative Consonants [v s z v^j s^j z^j] in the Context of the Vowel [a].

Among the plain fricative consonants, only [v] and [z] were identified correctly at the Isolation Gate, 100% and 85%, respectively. The accuracy for [s] was poorer, only 45%. At the Recognition Gate, subjects' accuracy was very high, 100%. The accuracy level of their responses is consistent with the confidence level at these gates, as can be seen in Figures 4.6. (a), (b) and (c) below.

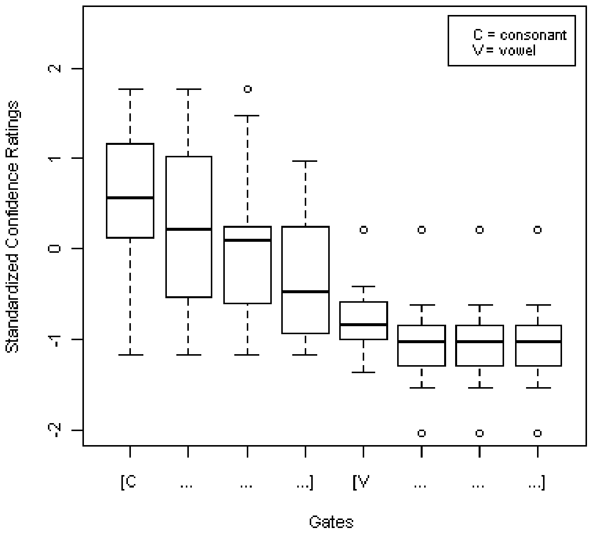


Figure 4.6.a. Boxplots of Confidence Rankings of all gates of Bulgarian [val], Audio-Visual Condition.

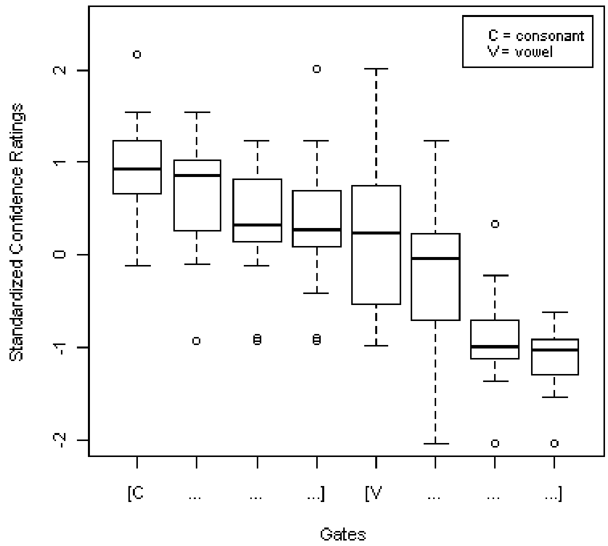


Figure 4.6.b. Boxplots of Confidence Rankings of all gates of Bulgarian [sal], Audio-Visual Condition

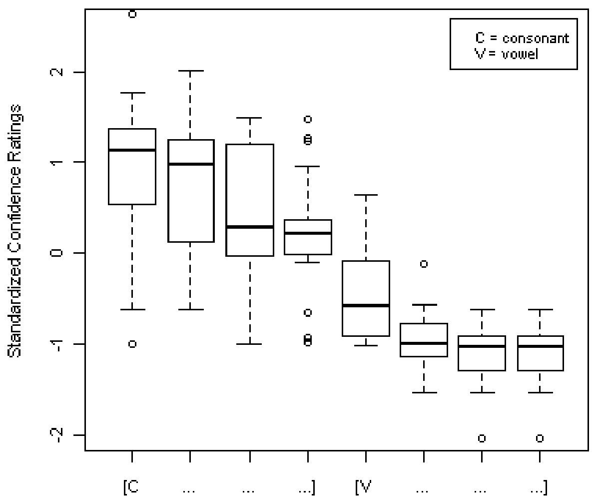


Figure 4.6.c. Boxplots of Confidence Rankings of all gates of Bulgarian [zapad], Audio-Visual Condition.

Separate One-Way Repeated Measures ANOVAs confirmed that the Gate factor was significant. When the Sphericity assumption was violated ([z]), the Greenhouse-Geisser corrections for departure of sphericity did not change the p-value (Table 4.5).

Table 4.5. Repeated Measures ANOVA of Confidence Ratings for Plain Fricative Consonants, [a] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/v/ Gates	2, 38	39	< 0.001 ***	p = 0.002	NA
/s/ Gates	2, 38	52	< 0.001 ***	p = 0.004	NA
/z/ Gates	2, 38	69	< 0.001 ***	p = 0.142	< 0.001 ***

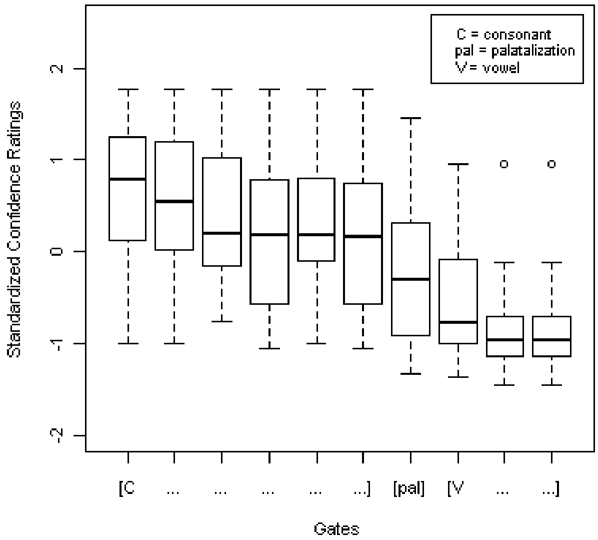
'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The mean confidence rankings for the critical gates (Table 4.5) show a rise in subjects' confidence level between these gates. Post-hoc analyses were conducted to establish if these differences were statistically significant. Pairwise t-tests confirmed that subjects were more confident at the Isolation Gate, compared to the Initial Gate: [v], $F(2,38) = 39$, $p < 0.001$; /s/, $F(2,38) = 52$, $p = 0.00066$; [z], $F(2,38) = 69$. However, the confidence level at the Isolation Gate of [s] is not as high as for the other two fricative consonants (Table 4.5). At the Recognition Gates, which incorporates the entire vowel information, subjects are very confident in their choice of all the tested plain fricative consonants.

Table 4.6. Confidence Ratings (in z-scores) for Plain Fricative Consonants, [a] Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/v/	20	0.47	2.96	0.88	- 0.78	1.58	0.34	- 1.10	1.42	0.33
/s/	20	0.90	2.28	0.53	- 0.21	3.00	0.84	- 1.11	1.42	0.33
/z/	20	0.93	3.64	0.83	- 0.47	1.66	0.49	- 1.11	1.42	0.33

The palatalized fricative consonants were poorly recognized: [s^j] at 50%, [z^j] at 5% (first [pal] gate) and 10% (second [pal] gate), and [v^j] at 20%. It is somewhat surprising that subjects' level of confidence for [z^j] had risen as much as the boxplots in Figure 4.7. b. show. The confidence rankings for the critical gates of [s^j] are shown in Figure 4.7.a. and those of [v^j] in Figure 4.7.c.



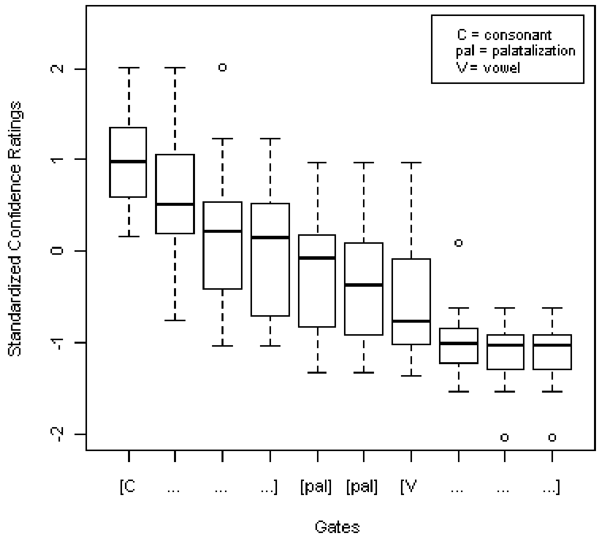


Figure 4.7.c. Boxplots of Confidence Rankings of all gates gates of Bulgarian [sʲal], Audio-Visual Condition

Figure 4.7.c. Boxplots of Confidence Rankings of all of Bulgarian [zʲapat], Audio-Visual condition

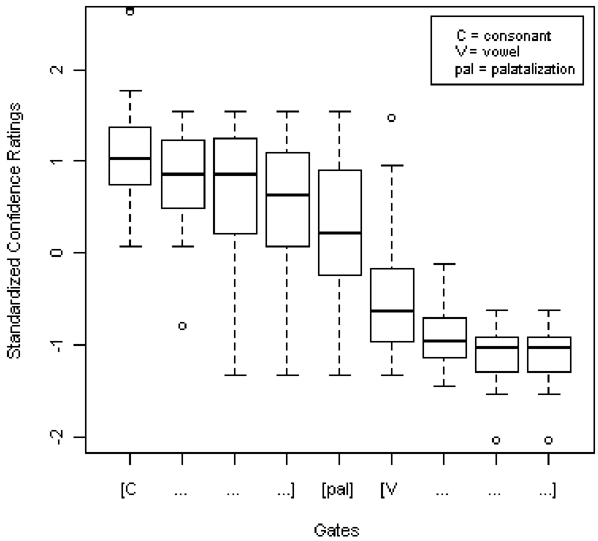


Figure 4.7.c. Boxplots of Confidence Rankings of all gates of Bulgarian [vʲal], Audio-Visual Condition

One-Way Repeated Measures ANOVAs were conducted for each of the palatalized fricative consonants which confirmed a main effect of the Gate factor. When the p-value associated with the Mauchly test of sphericity was larger than 0.05, the Greenhouse-Geisser correction for departure of sphericity was performed. The p-values for the Gate factor remained unchanged. The mean, range and standard deviation of the confident rankings for the critical gates of all consonants are given in Table 5.8.

Table 4.7. Repeated Measures ANOVA of Confidence Ratings for Palatalized Fricative Consonants, [a] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/v^j/ Gates	2, 38	89	< 0.001 ***	p = 0.724	< 0.001 ***
/s^j/ Gates	2, 38	23	< 0.001 ***	p = 0.689	< 0.001 ***
/z^j/ Gates	3, 57	164	< 0.001 ***	p = 0.008	NA

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4.8. Confidence Ratings (in z-scores) for Palatalized Fricative Consonants, /a/ Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			**Isolation Gate (1)**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/v^j/	20	1.13	2.62	0.68	- 0.27	2.88	0.82	- 1.10	1.42	0.33
/s^j/	20	0.68	2.78	0.80	- 0.24	2.79	0.76	- 0.85	2.42	0.53
/z^j/	20	0.98	1.85	0.52	- 0.24	2.31	0.60	- 1.11	1.42	0.33
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/z^j/	20				- 0.39	1.42	0.61			

For all consonants, the subjects felt more confident in their responses at the Isolation Gate, compared to the Initial Gate: [v^j], F(2,38) = 89, p = < 0.001; [s^j], F(2,38) = 23, p = 0.00022 ; [z^j], F(3,57) = 164, p < 0.001. It is important to note that, although subjects' mean confidence level at the second [pal] gate of [z^j] (Isolation Gate (2), Table 3.33) indicates that they felt 'fairly sure' in their responses, this figure is not statistically significant (Isolation (1) vs. Isolation (2), F(3,57) = 164, p = 0.39). In comparison to the Isolation Gate, subjects' confidence in their responses at the Recognition Gate approaches 'very sure', 1.2 on the standardized ranking scale.

4.3.3.5 Fricative Consonants [s s^j] in the Context of the Vowel [u].

These consonants were not identified very accurately at the Isolation Gate. Subjects identified them with an accuracy of 60% for [s] and 65% for [s^j]. The accuracy level is not improved even at the second [pal] gate of [s^j], 60%. An accuracy of 100% is achieved for both plain and palatalized consonants only at the Recognition Gate. The confidence level across gates is represented in Figures 4.8 (a) and (b). In both cases, confidence does not increase noticeably until the first [V] gate.

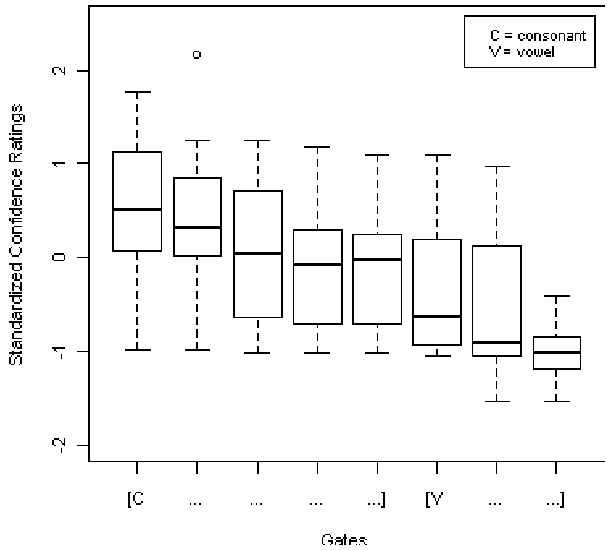


Figure 4.8.a. Boxplots of Confidence Rankings of all gates of Bulgarian [supa], Audio-Visual Condition

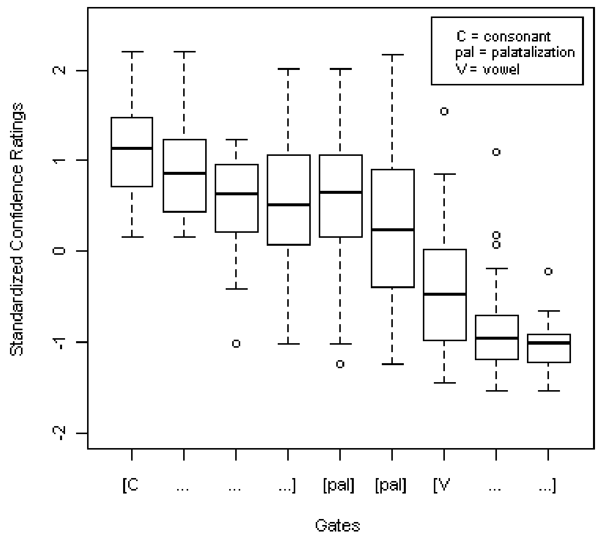


Figure 4.8.b. Boxplots of Confidence Rankings of all gates of Bulgarian [sju], Audio-Visual condition

For each consonant, a One-Way Repeated Measures ANOVA was performed (Table 4.9). The Gate factor was found to be significant. Due to violation of the sphericity assumption ($p = 0.342$, $p = 0.167$), the Greenhouse-Geisser correction to sphericity was applied. The correction procedure returned the same p-values, $p < 0.001$.

Table 4.9 Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [u] Context, Audio Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/s/ Gates	2, 38	40	< 0.001 ***	p = 0.342	< 0.001 ***
/sʲ/ Gates	3, 57	58	< 0.001 ***	p = 0.167	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

To establish if the mean differences of confidence rankings between the critical gates (Table 4.10) are statistically significant, further post-hoc analyses were performed. In relation to [s], subjects' confidence in their responses improved at the Isolation Gate ($F(2,38) = 40$, $p < 0.001$). Even though there was an increase of confidence from the Initial Gate to the Isolation Gate for [sʲ] ($F(3,57) = 58$, $p = 0.009$), this increase only translates from 'very unsure' to 'fairly unsure'. Furthermore, there was no increase in confidence between the two Isolation Gates ($p = 0.238$). Subjects' showed improved confidence at the Recognition Gates of both consonants ($p < 0.001$).

Table 4.10 Confidence Ratings (in z-scores) for Fricative Consonants, [u] Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/s/	20	0.56	2.75	0.68	- 0.35	2.13	0.70	-1.01	1.12	0.20
/sʲ/	20	1.09	2.04	0.57	0.45	3.26	0.87	-1.03	1.32	0.30
					Isolation Gate (2)					
					Mean	**Range**	**SD**			
/sʲ/	20				0.23	3.41	0.89			

4.3.2.6 Summary of Results – Fricative Consonants [v s z vʲ sʲ zʲ] in the Context of the Vowels [a] and [u].

Among the tested plain consonants, [s] was not identified with a high accuracy at the Isolation Gate in neither vowel environments ([sa], 45%; [su], 60%). The other two plain consonants, [v] and [z] were tested only in the context of the vowel [a]. They were identified more accurately at the Isolation Gate ([va], 100%; [za], 85%). All three consonants were identified with an accuracy of 100% at the Recognition Gate, in both of the vowel contexts for [s]. Subjects' response accuracy for the palatalized consonants was not very high either. Even when two [pal] gates were available, subjects were still making errors in identifying the fricative consonants [s^j] (in the context of [u], 60%) and [z^j] (in the context of [a], 15%) as palatalized. As with the plosive consonants, there was a similar pattern in subjects' confidence level at the Isolation Gate in the audio-visual condition. In comparison to the audio only condition, the confidence in their responses is not as high.

4.3.3.7 Approximants [l r n l^j r^j n^j] in the context of the vowel [a]

At the Isolation Gate, the plain consonants [l] and [r]were identified accurately, 90% and 100%, respectively. This was not the case with [n], 15%. All of the plain consonants were identified with high accuracy at the Recognition Gate, 100%. There was also a high level of accuracy at the Isolation Gates of the palatalized consonants: [l^j] at 100%, [n^j] at 80 %, and [r^j] at 70%. Note that in the case of [r^j] and [n^j], subjects had only partial information on palatalization available at the [pal] (Isolation) gate. For all consonants, plain and palatalized, there was also an increase in confidence at the Isolation Gate, in comparison to the preceding gates, as can be seen in Figures 4.12. a – f. At the point of the Recognition Gate, the level of confidence was even higher, around '-1', which approached 'very sure' (-1.2) on the standardized rating scale.

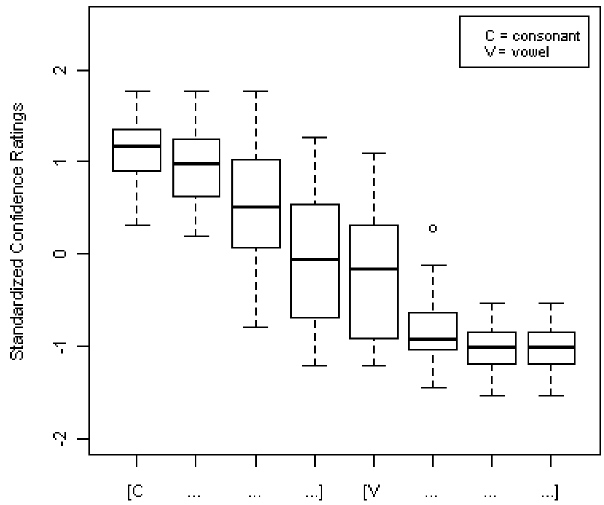


Figure 4.12.a. Boxplots of Confidence Rankings of all gates of Bulgarian [lava], Audio-Visual Condition

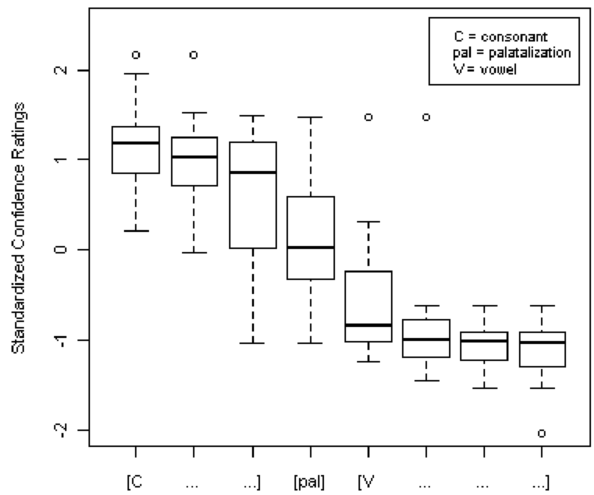


Figure 4.12.b. Boxplots of Confidence Rankings of all gates of Bulgarian [lʲava], Audio-Visual condition

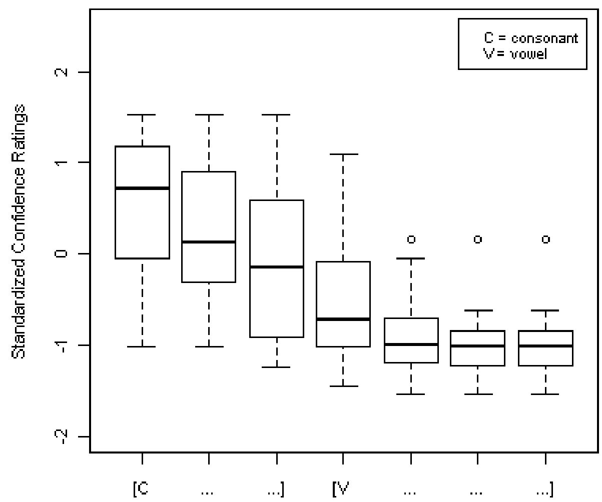


Figure 4.12.c. Boxplots of Confidence Rankings of all gates gates of Bulgarian [radka], Audio-Visual Condition

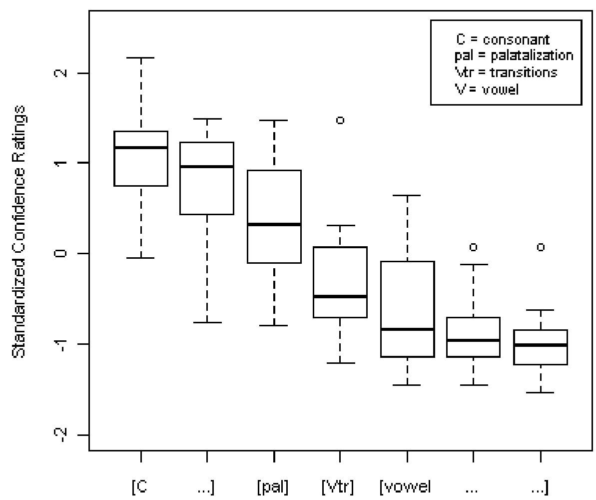


Figure 4.12.d. Boxplots of Confidence Rankings of all of Bulgarian [rʲadka], Audio-Visual condition

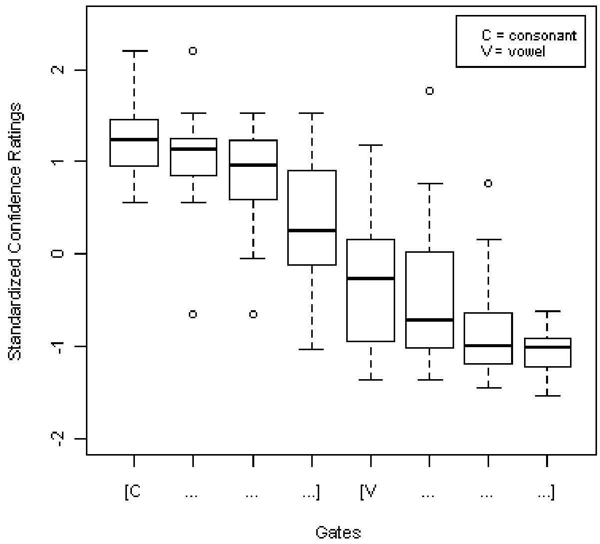


Figure 4.12.e. Boxplots of Confidence Rankings of all gates of Bulgarian [nam], Audio-Visual Condition

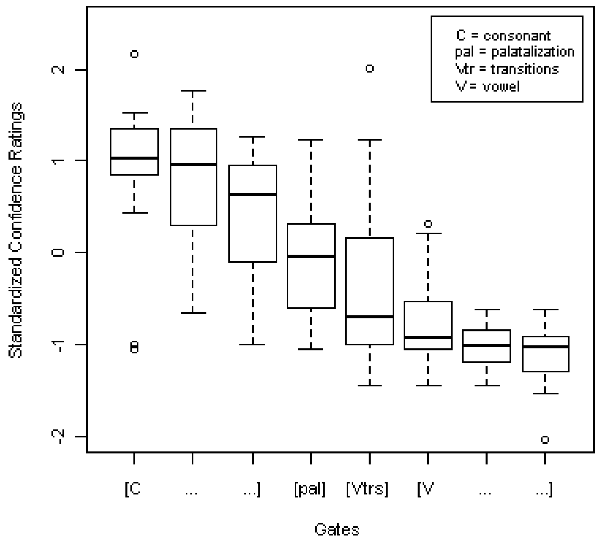


Figure 4.12.f. Boxplots of Confidence Rankings of all gates of Bulgarian [nʲam, Audio-Visual condition

To find out if the mean differences in confidence rankings at the critical gates were statistically significant, separate One-Way Repeated Measures ANOVAs were performed. There was a main effect of Gate for all consonants (Table 5.10). When the sphericity condition was violated, the Greenhouse-Geisser corrections for departure of sphericity were performed. The returned p-values remained unchanged (Table 5.10).

Table 4.10. Repeated Measures ANOVA of Confidence Ratings for Approximants, /a/ Context, Audio-Visual Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/l/ Gates	2, 38	117	< 0.001 ***	p = 0.014	< 0.001 ***
/lʲ/ Gates	2, 38	82	< 0.001 ***	p = 0.154	< 0.001 ***
/r/ Gates	2, 38	29	< 0.001 ***	p = 0.096	< 0.001 ***
/rʲ/ Gates	3, 57	68	< 0.001 ***	p = 0.015	< 0.001 ***
/n/ Gates	2, 38	113	< 0.001 ***	p = 0.009	NA
/nʲ/ Gates	3, 57	36	< 0.001 ***	p = 0.246	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4.11 shows the mean, range and standard deviation of confidence rankings for the critical gates of all consonants. The [Vtr] gate was also included in the analyses to find out if the accumulation of visual cues would significantly improve subjects' confidence in comparison to the Isolation Gate. Subsequent to the ANOVAs, additional post-hoc analyses were performed to establish which mean differences bore statistical significance.

Table 4.11. Confidence Ratings (in z-scores) for Approximants, [a] Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l/	20	1.12	1.47	0.36	- 0.21	2.30	0.72	- 1.01	1.01	0.27
$/l^j/$	20	1.14	1.94	0.47	- 0.13	2.51	0.73	- 1.11	1.42	0.33
/r/	20	0.47	2.55	0.84	- 0.60	2.54	0.62	- 1.00	1.70	0.37
$/r^j/$	20	1.05	2.20	0.54	- 0.35	2.26	0.66	- 1.00	1.61	0.36
/n/	20	1.21	1.64	0.36	- 0.28	2.54	0.70	- 1.05	0.93	0.25
$/n^j/$	20	0.93	3.21	0.77	- 0.06	2.28	0.66	- 1.11	1.42	0.33
					Vowel Transitions					
					Mean	**Range**	**SD**			
$/r^j/$	20				- 0.74	1.04	0.32			
$/n^j/$	20				- 0.35	1.42	0.89			

Pairwise t-tests between the [pal] and [Vtr] gates of palatalized [r^j] and [n^j] indicated that subjects' confidence increased at the [Vtr] gate of [r^j] ($F(3,57) = 68$, $p < 0.001$) but not [n^j] ($F(3,57) = 36$, $p = 0.1882$). Further t-tests between the [Vtr] and the last [V] gate of the consonants showed that the increase in confidence ranking is significant for [n^j] ($p = 0.0018$) but not for [r^j] ($p = 0.099$). The increase in confidence between the Isolation and Recognition Gates only approached significance ($F(2,38) = 29$, $p = 0.053$) for [r], but was significant for [l] ($F(2,38) = 117$, $p < 0.001$) , [l^j] ($F(2,38) = 82$, $p < 0.001$) and [n] ($F(2,38) = 113$, $p < 0.001$). For all consonants, [l r n l^j r^j n^j], the increase in confidence between the Initial and Isolation Gates was statistically significant, $p < 0.001$.

4.3.3.8 Approximants [l r n l^j r^j n^j] in the context of the vowel [u]

At the Isolation Gate, the accuracy for the plain approximants was average, overall: [l] at 60%, [r] at 100%, and [n] at 55%. The results were similar for the palatalized consonants: [l^j] at 90%, [r^j] at 65%, and[n^j] at 65%. At the Recognition Gate, the performance was flawless for all consonants, 100%. Figures 5.13. a – f show the confidence rankings across all gates of the plain and palatalized approximants. In general, beginning from the Initial Gate, the first significant rise of confidence occurs at the Isolation Gate. The biggest increase of confidence can be seen at the Recognition Gate, or the last [V] gate of each consonant.

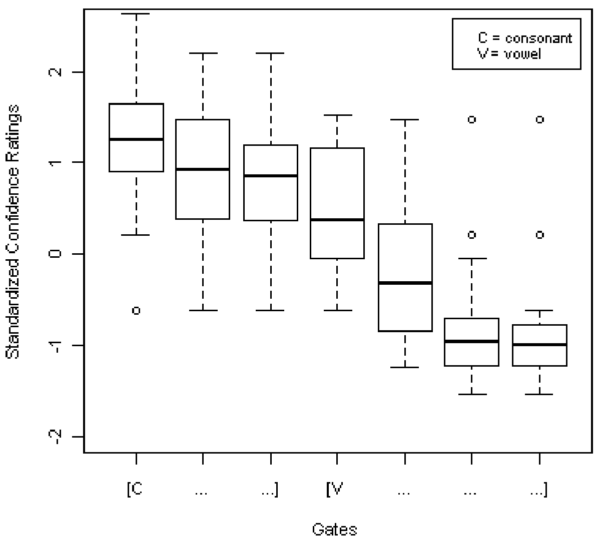


Figure 4.13.a. Boxplots of Confidence Rankings of all gates Bulgarian [luk], Audio-Visual Condition

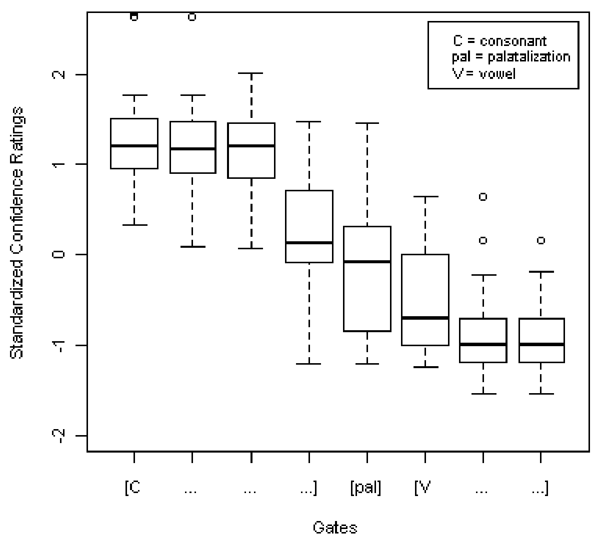


Figure 4.13.b. Boxplots of Confidence Rankings of of all gates of Bulgarian [l^juk], Audio-Visual condition

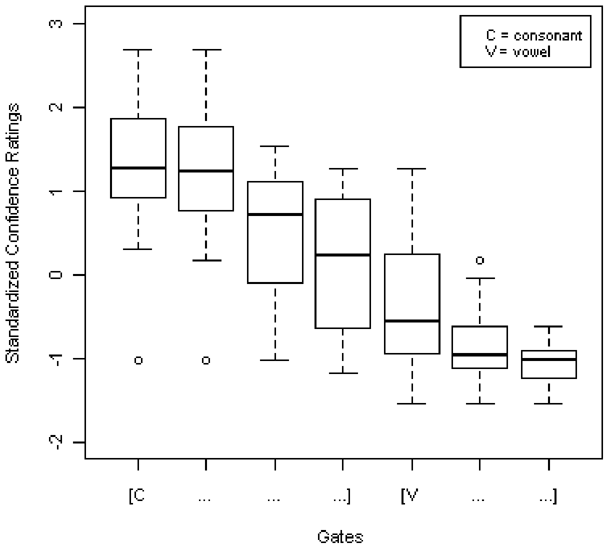


Figure 4.13.c. Boxplots of Confidence Rankings of all gates of Bulgarian [rup], Audio-Visual Condition
Condition

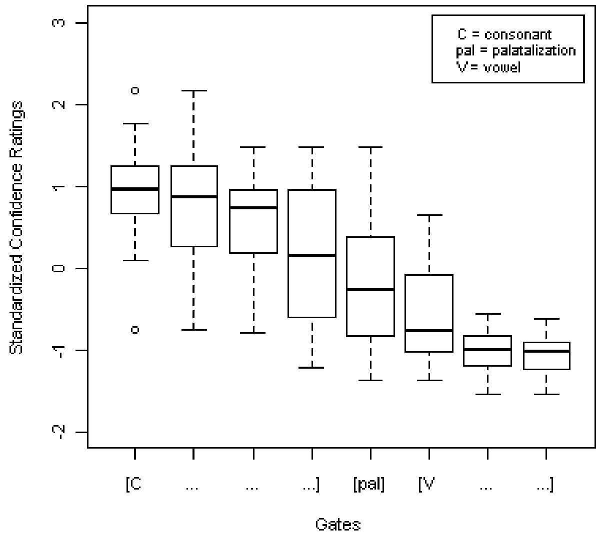


Figure 4.13.d. Boxplots of Confidence Rankings of all gates of Bulgarian [r^jup], Audio-Visual

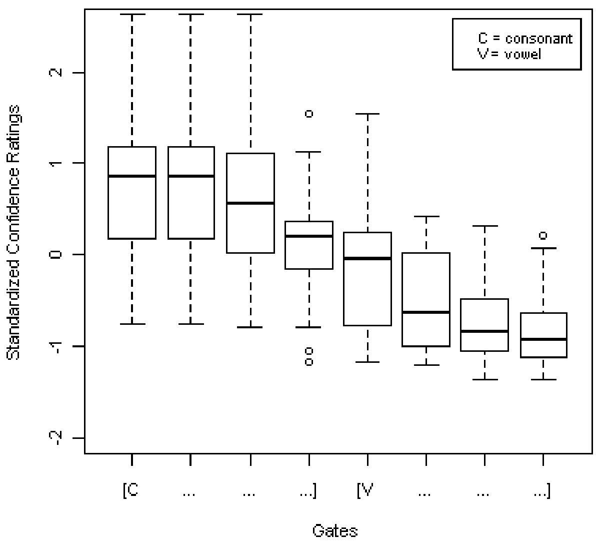


Figure 4.13.e. Boxplots of Confidence Rankings of all gates of Bulgarian [nuga], Audio-Visual Condition
Condition

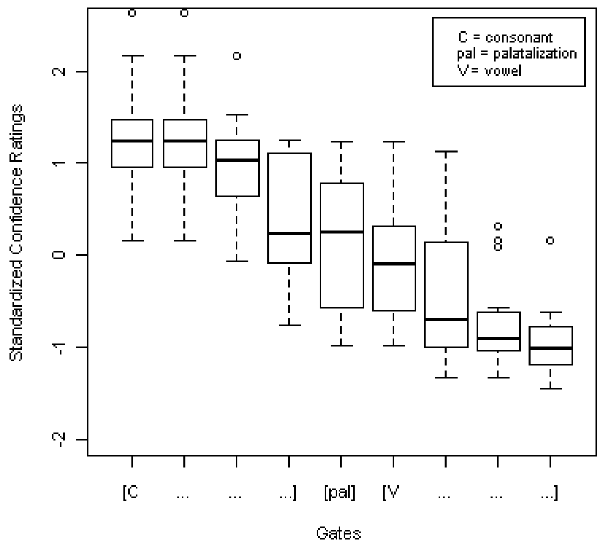


Figure 4.13.f. Boxplots of Confidence Rankings of all gates of Bulgarian [n^jux], Audio-Visual

For each consonant, a One-Way Repeated Measures ANOVA established a main effect of the Gate factor (Table 4.12). When the sphericity condition was violated, the Greenhouse-Geisser corrections for the departure of sphericity were applied. The returned p-values did not change.

Table 4.12 Repeated Measures ANOVA of Confidence Ratings for Approximants, [u] Context, Audio-Visual Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/l/ Gates	2, 38	72	< 0.001 ***	p = 0.307	< 0.001 ***
/lʲ/ Gates	2, 38	68	< 0.001 ***	p = 0.171	< 0.001 ***
/r/ Gates	2, 38	68	< 0.001 ***	p = 0.266	< 0.001 ***
/rʲ/ Gates	2, 38	47	< 0.001 ***	p = 0.087	< 0.001 ***
/n/ Gates	2, 38	51	< 0.001 ***	p = 0.011	NA
/nʲ/ Gates	2, 38	59	< 0.001 ***	p = 0.149	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The mean, range and standard deviation of the critical gates of all consonants is displayed in Table 4.13. Pairwise comparisons between the Initial and Isolation Gates of all consonants confirmed that the increase in subjects' confidence is statistically significant: [l], F(2,38) = 72, p = 0.0012; [r], F(2,38) = 68, p < 0.001; [n], F(2,38) = 51, p < 0.001; [lʲ], F(2,38) = 68, p < 0.001; [rʲ], F(2,38) = 47, p < 0.001; [nʲ], F(2,38) = 59, p < 0.001. The mean difference in confidence ranking between the Isolation and Recognition Gates is also statistically significant ([n], p = 0018; [r], p = 00097; and for the rest of the consonants, p < 0.001).

Table 4.13 Confidence Ratings (in z-scores) for Approximants, [u] Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			**Isolation Gate**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l/	20	1.25	3.25	0.73	- 0.50	2.14	0.70	- 0.86	3.01	0.77
/lʲ/	20	1.28	2.36	0.60	- 0.16	2.67	0.74	- 0.91	1.70	0.41
/r/	20	1.31	3.71	0.83	- 0.29	2.80	0.82	- 1.05	0.93	0.25
/rʲ/	20	0.93	2.92	0.62	- 0.16	2.84	0.82	- 1.05	0.59	0.25
/n/	20	0.73	3.40	0.77	- 0.19	2.72	0.66	- 0.84	1.58	0.41
/nʲ/	20	1.23	2.47	0.57	- 0.13	2.22	0.72	- 0.95	1.62	0.36

4.3.3.9 Summary of Results – Approximants [l r n l^j r^j n^j] in the context of the Vowels [a] and [u].

Among the plain approximates, subjects were least accurate at the Isolation Gate of [n], in both vowel contexts. The consonants [l] and [r] were identified more accurately, although the accuracy for [l] in the context of [a] was just above chance, 60%. With regards to the palatalized consonants, [l^j] was identified accurately at the Isolation Gate in both vowel environments. However, [r^j] and [n] were identified more accurately in the context of the vowel [a]. Overall, there was a considerable increase in the level of confidence at the Isolation Gate, compared to the Initial Gate. For the majority of the consonants, in both vowel contexts, there was a significant increase of confidence at the Recognition Gate. In comparison to the audio only condition, in the audio-visual condition subjects showed less confidence at the Identification Gate.

4.3.4 Results: Russian Subjects.

4.3.4.1 Plosive Consonants [t d t^j d^j] in the Context of the Vowel [a].

With the exception of /t/ (55%), the rest of the plosive consonants were perceived accurately at the Identification Gate: /t^j/ at 82%, /d/ at 91% and /d^j/ at 82%. Note that at the [pal] gate of /t^j/, only partial information on palatalization was available. The palatalized /d^j/ was identified with an accuracy of 95% at the Recognition Gate. For the rest of the consonants, subjects' precision reached 100% at the same gate. Figures 4.16. (a), (b), (c) and (d) represent boxplots of confidence rankings for these consonants across all gates. As can be seen, the level of confidence mirrors the response accuracy with which consonants are identified as plain or palatalized in all cases but one, the palatalized /t^j/.

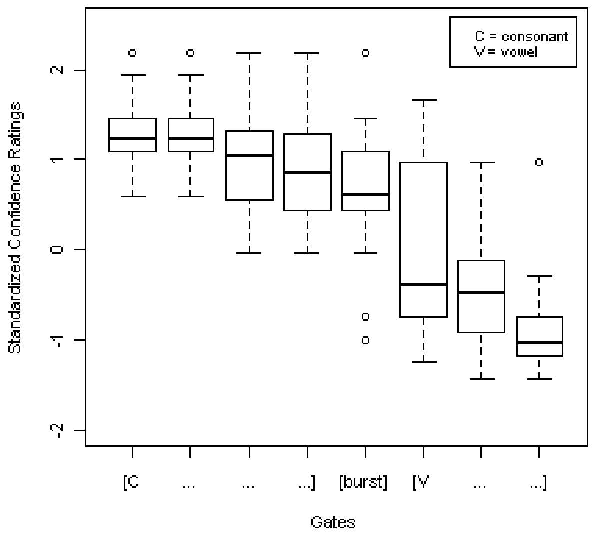


Figure 4.16.a. Boxplots of Confidence Rankings of all gates gates of /Russian [tak], Audio-Visual Condition

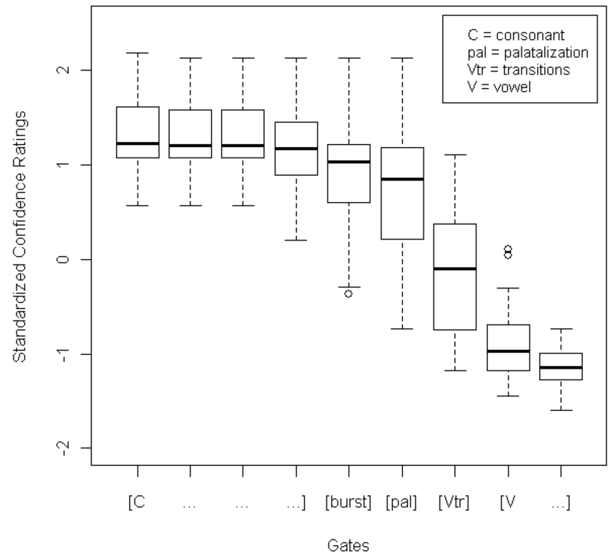


Figure 4.16.b. Boxplots of Confidence Rankings of all gates of Russian [tʲag], Audio-Visual Condition

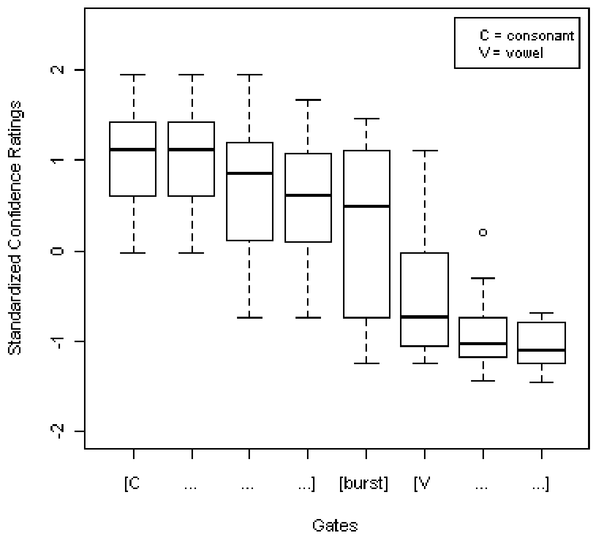


Figure 4.16.c. Boxplots of Confidence Rankings of all gates of Russian [datelj], Audio-Visual Condition

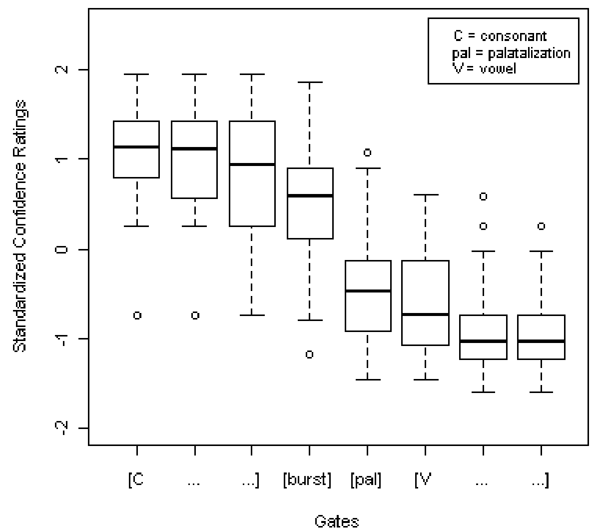


Figure 4.16.d. Boxplots of Confidence Rankings of all gates of Russian [dʲatel], Audio-Visual condition

For each consonant, a separate One-Way Repeated Measures ANOVA was performed which establish a main effect of gate, Table 4.14. When the Mauchly test indicated that the sphericity assumption was violated, the Greenhouse-Geisser corrections for departure of sphericity were applied. The returned p-values remained unchanged.

Table 4.14 Repeated Measures ANOVA of Confidence Rankings for Plosive Consonants, [a] Context, Audio-Visual Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/t/ Gates	2, 42	68	< 0.001 ***	p = 0.053	NA
/tʲ/ Gates	3, 63	103	< 0.001 ***	p = 0.0004	NA
/d/ Gates	2, 42	104	< 0.001 ***	p = 0.064	< 0.001 ***
/dʲ/ Gates	2, 42	65	< 0.001 ***	p = 0.432	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Pairwise t-tests were employed to find out if the mean differences in confidence rankings among the critical gates (Table. 4.15) were statistically significant. Compared to the Initial Gate, subjects were more confident in their responses at the Isolation Gate. This result applied to all consonants: /t/, $F(2,42) = 68$, $p < 0.001$; /tʲ/, $F(3.63) = 103$, $p = 0.00099$; /d/, $F(2,42) = 104$, $p < 0.001$; /dʲ/, $F(2,42) = 65$; $p < 0.001$). However, subjects were not more confident at the [Vtr] than at the [pal] gate of /tʲ/. For all consonants, subjects were most confident at the Recognition Gate, $p < 0.001$.

Table 4.15 Confidence Ratings (in z-scores) for Plosive Consonants, /a/ Context, Audio-Visual Condition, Russian subjects.

		Initial Gate			Isolation Gate			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/t/	22	1.30	1.59	0.38	- 0.04	2.92	0.96	- 0.90	2.42	0.50
/tʲ/	22	1.32	1.62	0.45	0.74	2.86	0.73	- 1.13	0.86	0.25
/d/	22	1.04	1.98	0.52	- 0.45	2.36	0.70	- 1.07	0.76	0.25
/dʲ/	22	1.04	2.69	0.60	- 0.43	2.53	0.69	- 0.92	1.85	0.46
					Vowel Transitions					
					Mean	**Range**	**SD**			
/tʲ/	22				- 0.14	2.29	0.69			

4.3.4.2 Plosive Consonants [t d t^j d^j] in the Context of the Vowel [u].

Russian subjects were very accurate in determining if any of these consonants was plain or palatalized in the environment of the vowel /u/ at the Isolation Gate: /t/, 100%; /t^j/, 77%; /d/, 91%; /d^j/, 86%. However, at the Recognition Gate they recognized only /t/ with a 100% accuracy. The rest of the consonants were identified with an accuracy of 95% at this gate. This accuracy was also reflected in the subjects' level of confidence for all consonants but /d/. Confidence rankings for all consonants across gates are represented in Figures 4.17 (a), (b), (c) and (d)).

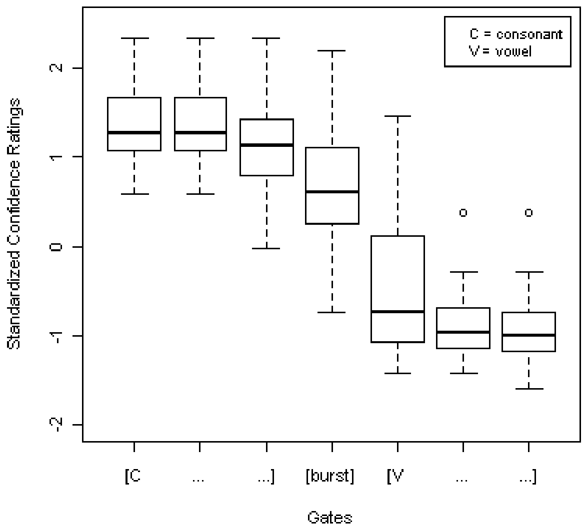


Figure 4.17.a. Boxplots of Confidence Rankings of all gates of Bulgarian [tuk], Audio-Visual Condition

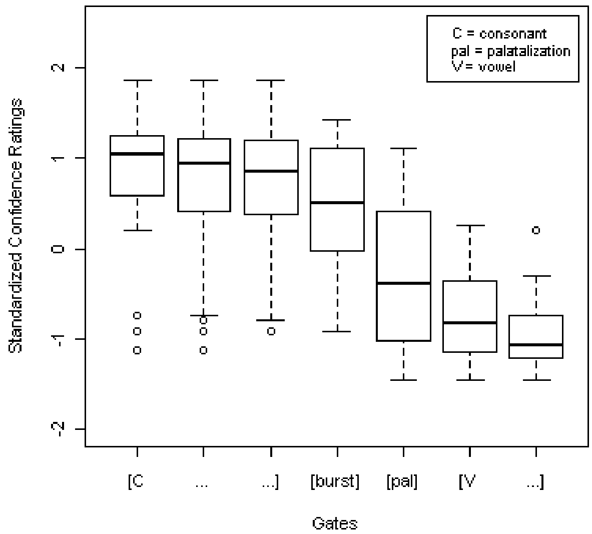


Figure 4.17.b. Boxplots of Confidence Rankings of all gates of Bulgarian [t^juk], Audio-Visual Condition

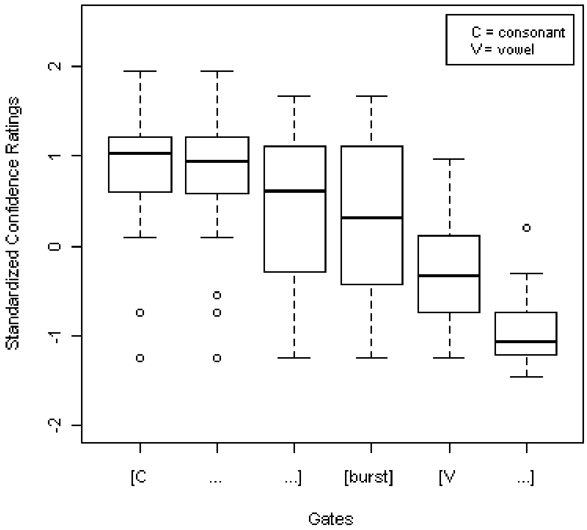


Figure 4.17.c. Boxplots of Confidence Rankings of all gates of Bulgarian [dunut^j], Audio-Visual Condition

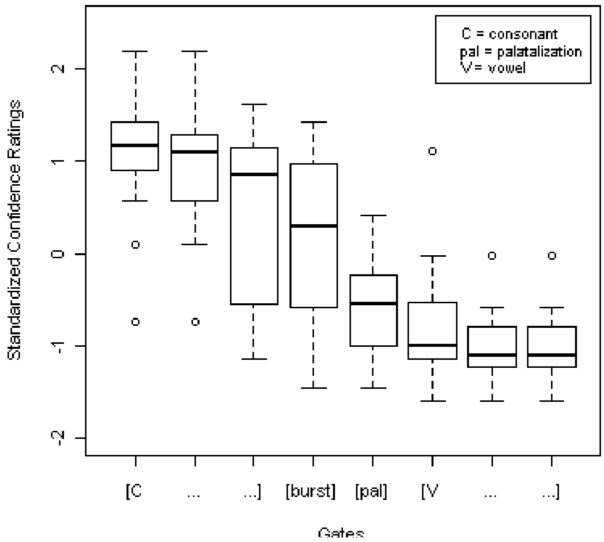


Figure 4.17.d. Boxplots of Confidence Rankings of all gates of Bulgarian [d^{j}una], Audio-Visual condition

Separate One-Way Repeated Measures ANOVAs were conducted for all consonants. A main effect of Gate was found. As the sphericity condition was violated for all consonants, Greenhouse-Geisser corrections for departure from sphericity were performed. These returned the same p-values, as shown in Table 4.16. Mean, range and standard deviations for all consonants are displayed in Table 4.17.

Table 4.16 Repeated Measures ANOVA of Confidence Rankings for Plosive Consonants, [u] Context, Audio Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/t/ Gates	2, 42	84	< 0.001 ***	p = 0. 055	< 0.001 ***
/t^j/ Gates	3, 63	37	< 0.001 ***	p = 0. 201	< 0.001 ***
/d/ Gates	2, 42	20	< 0.001 ***	p = 0.556	< 0.001 ***
/d^j/ Gates	2, 42	166	< 0.001 ***	p = 0.588	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4.17 Confidence Ratings (in z-scores) for Plosive Consonants, [u] Context, Audio-Visual Condition, Russian subjects.

		Initial Gate			Isolation Gate			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/t/	22	1.36	1.73	0.49	- 0.42	0.81	2.88	- 0.88	1.96	0.44
/t^j/	22	0.78	2.99	0.79	- 0.29	2.56	0.83	- 0.96	1.65	0.38
/d/	22	0.82	3.20	0.72	0.27	2.92	0.87	- 0.35	2.22	0.60
/d^j/	22	1.48	3.02	0.64	- 0.45	2.52	0.68	- 0.85	0.76	0.20

Following the ANOVAs, pairwise t-tests were conducted to establish if the mean difference in confidence rankings between the critical gates were statistically significant. The difference in confidence between the Initial and Isolation Gates of /d/ ($F(2,42)$, $p = 0.016$) approached significance. It should be noted, though, that the change in the level of confidence for /d/ was a marginal shift from 'very unsure' to 'fairly unsure'. For the rest of the consonants, subjects' confidence increased considerably at the Isolation Gate: /d^j/, $F(2,42) = 166$, $p < 0.001$; /t/, $F(2,42) = 20$, , $p < 0.001$; /t^j/, $F(3,63) = 37$, $p < 0.001$. The mean difference in confidence ranking between the Isolation and Recognition Gates approached significance for the plain consonants /t/ ($p = 0.015$), but was statistically significant for the consonants /d/ ($p = 0.013$), /t^j/ ($p = 0.0024$) and /d^j/ ($p = 0.0017$).

4.3.4.3 Summary of Results – Plosive Consonants [t d t^j d^j] in the Context of the Vowels [a] and [u].

With the exception of /t/ (55%) in the context of /a/, all consonants were identified accurately (at least 80%) in the environment of both vowels at the Isolation Gate. Overall, subjects felt 'fairly sure' (0.4 on the standardized ranking scale) in the accuracy of their responses at this gate. The most confidence was displayed at the Recognition Gate. It should be noted that subjects felt more confident at the Isolation Gate in the audio only condition, compared to the audio-visual condition, for all consonants and vowel contexts.

4.3.4.4 Fricative Consonants [v s z v^j s^j z^j] in the Context of the Vowel [a].

Only the plain fricative consonants /v/ and /z/ were identified fairly accurately at the Isolation Gate, 96% and 73%, respectively. The plain /s/ was perceived very poorly at this gate. Among the palatalized fricative consonants, only /v^j/ was identified with any precision, 82%. The Russian subjects failed to identify /s^j/ and /z^j/ accurately, 27% and 36%, respectively. At the Recognition Gate, the accuracy went up to 100%. Confidence levels at the Isolation and Recognition Gates reflect subjects' response accuracy at these gates. Figures 4.20 (a), (b), (c), (d), (e) and (f) represent the confidence rankings across gates for all the consonants. Table 4.27 shows the mean, range and standard deviation of confidence rankings at the critical gates.

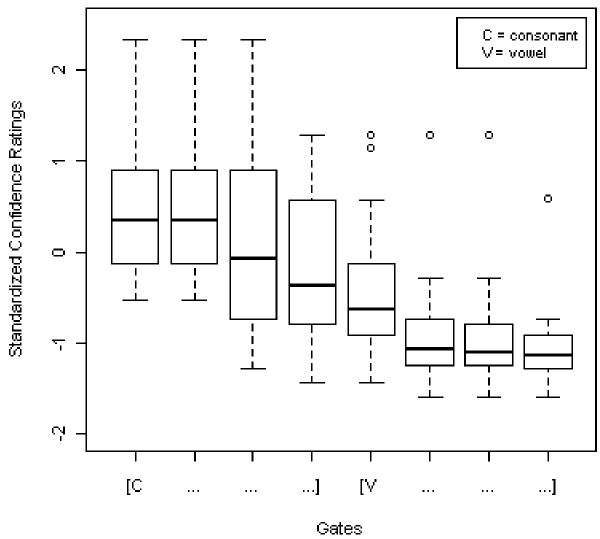


Figure 4.20.a. Boxplots of Confidence Rankings of all gates Russian [val], Audio-Visual Condition

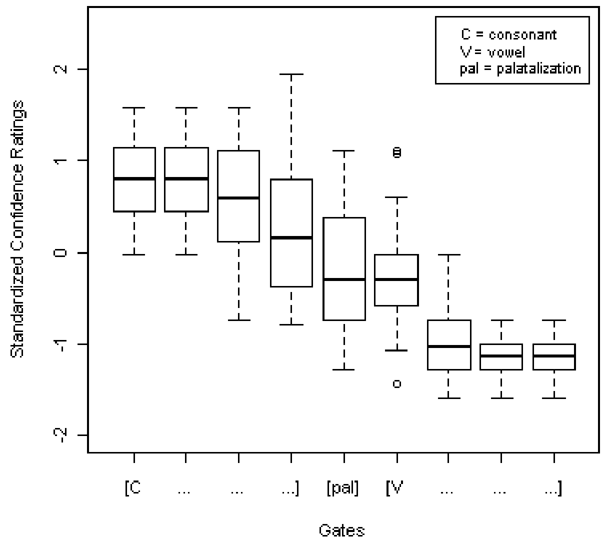


Figure 4.20.a. Boxplots of Confidence Rankings of all gates of Russian [v^jal], Audio-Visual condition

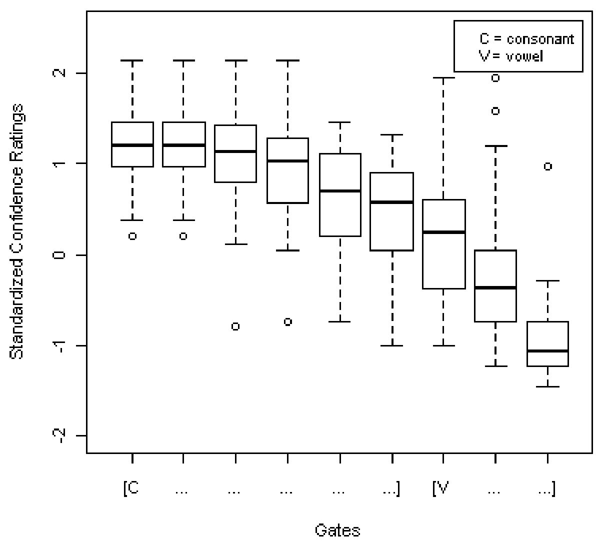


Figure 4.20.c. Boxplots of Confidence Rankings of all gates of Russian [sad], Audio-Visual Condition

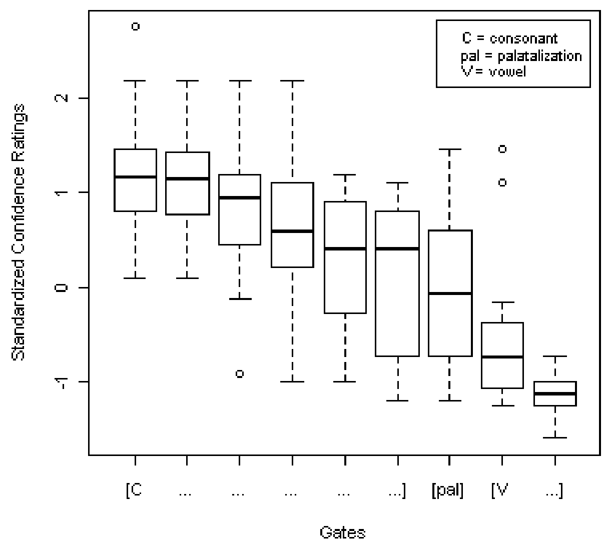


Figure 4.20.d. Boxplots of Confidence Rankings of all gates of Russian [s^jad], Audio-Visual condition

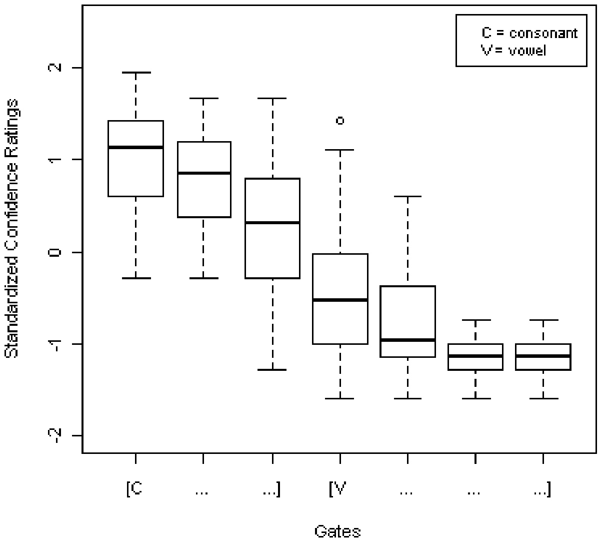


Figure 4.20.c. Boxplots of Confidence Rankings of all gates Russian [zapad], Audio-Visual Condition

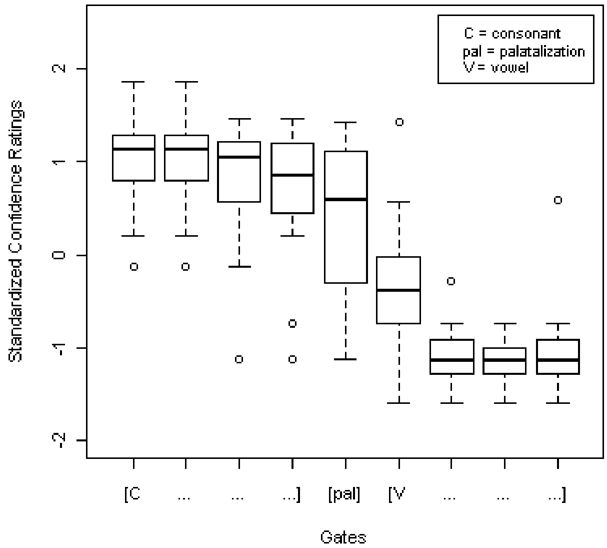


Figure 4.20.d. Boxplots of Confidence Rankings of all gates of of Russian [z^j abj], Audio-Visual condition

Table 5.18 Confidence Ratings (in z-scores) for Fricative Consonants, [a] Context, Audio-Visual Condition, Russian subjects.

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/v/	22	0.44	2.84	0.72	- 0.47	2.71	0.74	- 1.10	3.08	0.53
/v^j/	22	0.80	1.61	0.46	- 0.19	2.38	0.68	- 1.18	1.76	0.38
/s/	22	1.22	1.92	0.45	0.22	2.95	0.77	- 0.95	2.42	0.52
/s^j/	22	1.18	2.65	0.65	- 0.03	2.65	0.81	- 1.11	0.86	0.24
/z/	22	1.13	3.44	0.80	- 0.41	3.01	0.77	- 1.18	1.76	0.38
/z^j/	22	1.04	1.98	0.45	0.38	2.55	0.82	- 1.10	3.08	0.53

Separate One-Way ANOVAs were performed for each consonant and a main effect of Gate was established. Except for /v/ and /z^j/, the sphericity assumption was violated. Thus, the Greenhouse-Geisser corrections for the departure to specificity were applied (Table 4.19).

Table 4.19 Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [a] Context, Audio-Visual Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/v/ Gates	2, 42	35	< 0.001 ***	p = 0.012	NA
/v^j/ Gates	2, 42	90	< 0.001 ***	p = 0.101	< 0.001 ***
/s/ Gates	2, 42	68	< 0.001 ***	p = 0.087	< 0.001 ***
/s^j/ Gates	2, 42	103	< 0.001 ***	p = 0.194	< 0.001 ***
/z/ Gates	2, 42	90	< 0.001 ***	p = 0.141	< 0.001 ***
/z^j/ Gates	2, 42	42	< 0.001 ***	p = 0.01	NA

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

In comparison to the Initial Gate, there was a significant increase in confidence at the Isolation Gate for all consonants: /v/, $F(2,42) = 35$, $p < 0.001$; /v^j/, $F(2,42) = 90$, $p < 0.001$; /s/, $F(2,42) = 68$, $p < 0.001$; /s^j/, $F(2,42) = 103$, $p = 0.00093$; /z/, $F(2,42) = 90$, $p < 0.001$; /z^j/, $(2,42) = 42$, $p < 0.001$. However, for /s/ and /s^j/ the rise of confidence was marginal, 0.22 and – 0.03, respectively. Subjects were most confident in their responses at the Recognition Gate: /v/, $p = 0.0026$; /v^j/, $p < 0.001$; /s/, $p < 0.001$; /s^j/, $p < 0.001$; /z/, $p = 0.00033$; /z^j/, $p < 0.001$.

4.3.4.5 Fricative Consonants [s s^j] in the Context of the Vowel [u].

The plain consonant was identified accurately at the Isolation Gate, 82%. However, subjects' identification of the palatalized consonant at the same gate was poor, 27%. The response accuracy for /**s^j**/ did not improve even at the following [V] gate. Confidence rankings across gates are displayed in Figures 4.21. (a) and (b). Response accuracy at the Isolation Gate is reflected by the level of confidence, as the boxplots show. For both consonants, the first significant increase in confidence occurs only at the second [V] gate.

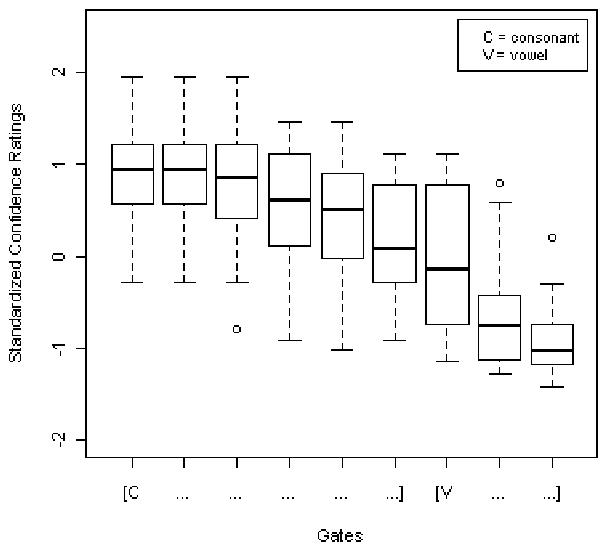


Figure 4.21.a. Boxplots of Confidence Rankings of all gates of Russian [sup], Audio-Visual Condition

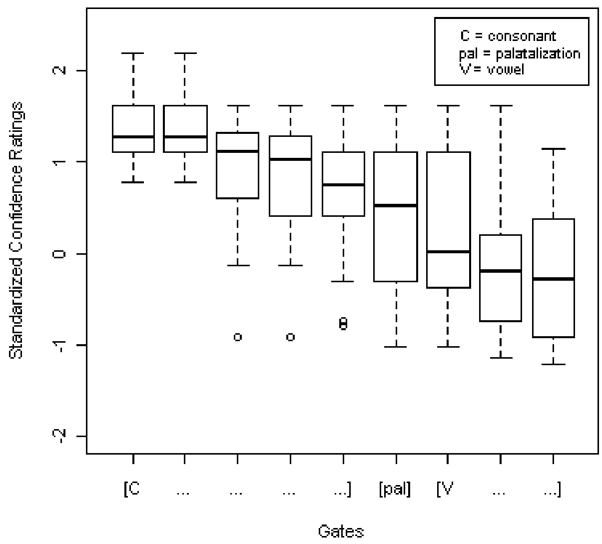


Figure 4.21.b. Boxplots of Confidence Rankings of all gates of Russian [s^ju], Audio-Visual condition

Table 4.20. shows the results from the One-Way Repeated Measures ANOVAs which show that the Gate factor bears significance for both consonants. Violations of sphericity were corrected with the Greenhouse-Geisser procedure.

Table 4.20 Repeated Measures ANOVA of Confidence Ratings for Fricative Consonants, [u] Context, Audio-Visual Condition, Bulgarian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/s/ Gates	2,38	40	< 0.001 ***	p = 0.342	< 0.001 ***
/s^j/ Gates	2,38	58	< 0.001 ***	p = 0.167	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

In addition to the ANOVAs, pairwise comparisons between the critical gates established if the mean difference in confidence rankings (Table 4.21.) were statistically significant. Russian subjects were more confident at the Isolation Gate (Initial vs. Isolation, /s/, $F(2,38) = 40$, $p < 0.001$; /s^j/, $F(2,38) = 58$, $p = 0.0098$). However, the increase in confidence at the Isolation Gate for /s^j/ was only a shift from 'very unsure' to 'fairly unsure'. Just as there was no increase in response accuracy at the first [V] gate (27%) for /s^j/, there was no increase of confidence at the same gate (Isolation vs. 1st [V], p =

0.3289). Subjects were most confident at the Recognition Gate (/s/, $p = 0.0008$; /sʲ/, $p < 0.001$).

Table 4.21. Confidence Ratings (in z-scores) for Fricative Consonants, /u/ Context, Audio-Visual Condition, Bulgarian subjects.

		Initial Gate			Isolation Gate			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/s/	22	0.85	2.23	0.54	- 0.07	2.26	0.78	- 0.91	1.63	0.38
/sʲ/	22	1.41	1.97	0.47	0.36	2.63	0.82	- 0.22	2.36	0.74

4.3.4.6 Summary of Results - Fricative Consonants [v s z vʲ sʲ zʲ] in the Context of the Vowel [a] and [s sʲ] in the Context of the Vowel [u].

Russian palatalized fricative consonants were poorly identified at the Isolation Gate. Subjects' response accuracy was low, between 25% and 36%. Admittedly, [sʲ] was identified accurately in the context of the vowel [a] at 82%, though, the level of confidence only approached 'fairly sure'. Subjects tended to be more accurate in identifying a consonant as plain. However, for the plain [s] in the environment of [a] their precision was very poor, 3%. At the Isolation Gate, confidence ratings generally reflected the response accuracy at the same gate.

4.3.4.7 Approximants [l lʲ r rʲ n nʲ] in the Context of the Vowel [a].

Overall, these consonants were identified accurately at the Isolation Gate. Both the plain and the palatalized alveolar trill were recognized with an accuracy of 100%. Subjects' accuracy for the plain /l/ and palatalized /lʲ/ was 95% and 91%, respectively. The nasal consonants, plain and palatalized, were identified with an accuracy of 64%. At the Recognition Gate, all consonants were identified flawlessly, 100%. Subjects' confidence ratings at the Identification and Recognition Gates reflect their response accuracy as the boxplots in Figures 4.24 (a), (b), (c), (d), (e) and (f) show. The first significant rise in confidence occurs at the Isolation Gate, except for the palatalized nasal consonant.

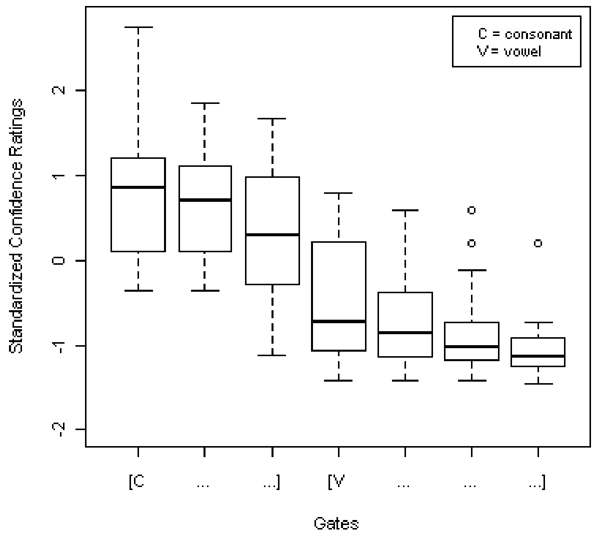


Figure 4.24.a. Boxplots of Confidence Rankings of all gates of Russian [lapa], Audio-Visual Condition

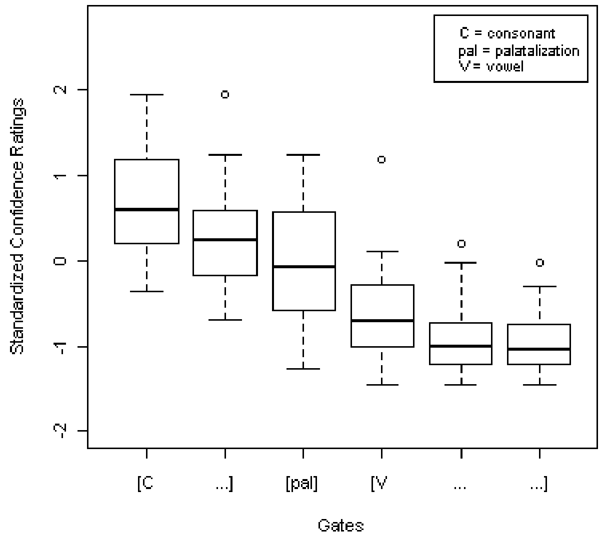


Figure 4.24.b. Boxplots of Confidence Rankings of all gates of Russian [$l^{j}apat^{j}$], Audio-Visual condition

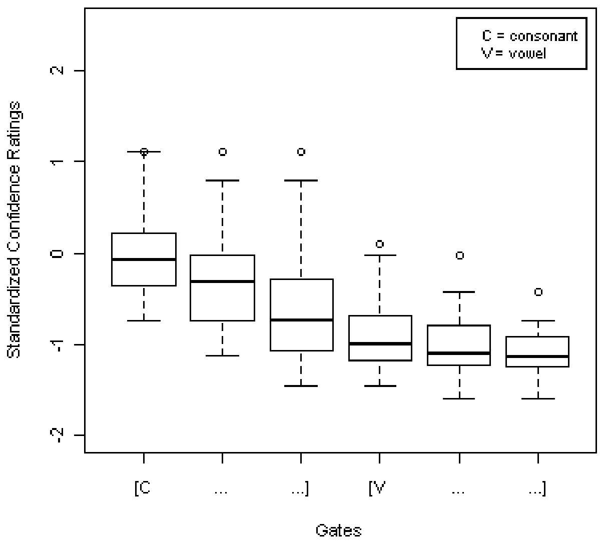


Figure 4.24.c. Boxplots of Confidence Rankings of all gates of Russian [rad], Audio-Visual Condition

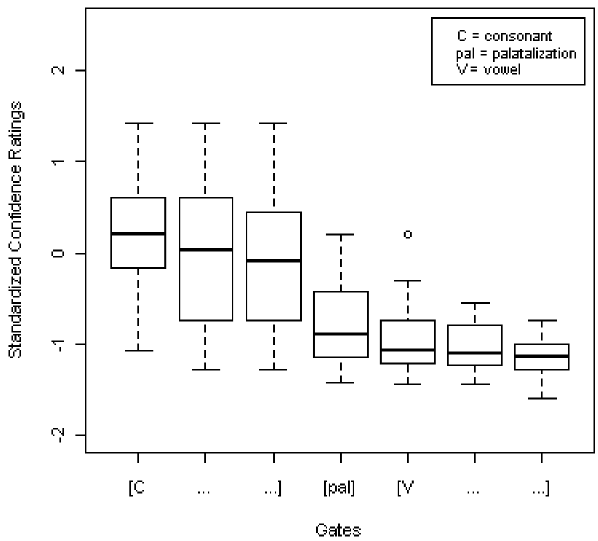
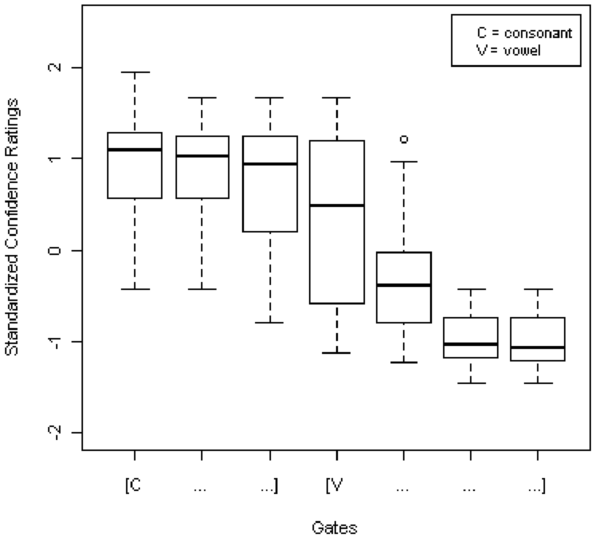


Figure 4.24.d. Boxplots of Confidence Rankings of all gates of Russian [$r^{j}ad$], Audio-Visual condition



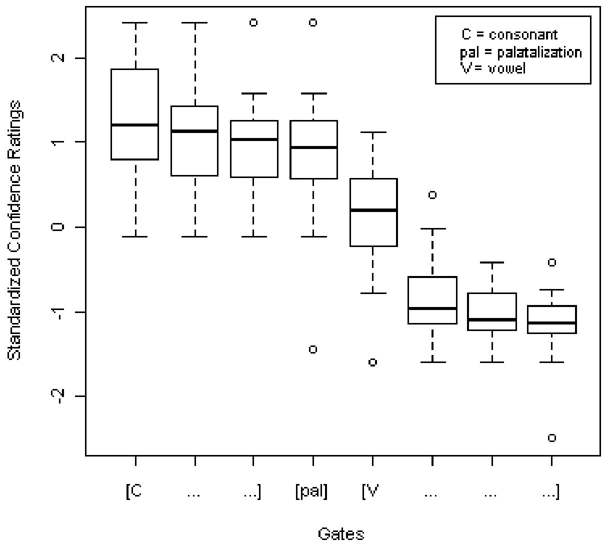


Figure 4.24.e. Boxplots of Confidence Rankings of all gates of Russian [nam], Audio-Visual Condition

Figure 4.24.f. Boxplots of Confidence Rankings of all gates of Russian [n^jam], Audio-Visual condition

Separate One-Way ANOVAs were conducted for each of the consonants. The analyses indicated a main effect of the Gate factor, Table 4.22. As the sphericity assumption was violated in all cases, the Greenhouse-Geisser corrections for departure from sphericity were applied.

Table 4.22 Repeated Measures ANOVA of Confidence Ratings for Approximants, [a] Context, Audio-Visual Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/l/ Gates	2, 42	20	< 0.001 ***	p = 0.55612	< 0.001 ***
/l^j/ Gates	2, 42	48	< 0.001 ***	p = 0.13175	< 0.001 ***
/r/ Gates	2, 42	56	< 0.001 ***	p = 0.17899	< 0.001 ***
/r^j/ Gates	2, 42	44	< 0.001 ***	p = 0.14751	< 0.001 ***
/n/ Gates	2, 42	56	< 0.001 ***	p = 0.1013	< 0.001 ***
/n^j/ Gates	2, 42	125	< 0.001 ***	p = 0.46493	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

For each consonant, pairwise comparisons between the critical gates were performed. The t-tests indicated that the increased confidence at the Isolation Gate approached significance for /n^j/ (F(2,42) = 125, p = 0.025), but was statistically significant for the rest of the consonants: /n/, F(2,42) = 56, p = 0.0023; /l/, F(2,42) = 20, p < 0.001; /l^j/, F(2,42) = 48, p = 0.00031; /r/, F(2,42) = 56, p < 0.001 ; /rʲ/, F(2,42) = 44, p < 0.001. However, for the nasal consonants, this increase in confidence was only a shift from 'very unsure' to 'fairly unsure'. The Russian subjects were most confident at the Recognition Gate (/n/; /nʲ/; /l/; /lʲ/; /rʲ/), though this rise in confidence was not statistically significant for /r/. This is not surprising as the mean average is already high at the Isolation Gate (Table 4.23).

Table 4.23 Confidence Ratings (in z-scores) for Approximants, [a] Context, Audio-Visual Condition, Russian Subjects

		Initial Gate			**Isolation Gate**			**Recognition Gate**		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l/	22	0.78	3.11	0.78	- 0.41	2.22	0.75	- 1.10	2.70	0.47
/lʲ/	22	0.70	2.31	0.66	0.01	2.52	0.69	- 0.93	1.43	0.41
/r/	22	0.03	1.86	0.52	- 0.85	1.54	0.44	- 1.08	1.18	0.28
/rʲ/	22	0.24	2.49	0.60	- 0.77	1.63	0.47	- 1.18	1.76	0.38
/n/	22	0.95	2.37	0.57	0.33	2.80	0.93	- 1.00	1.03	0.27
/nʲ/	22	1.26	2.53	0.69	0.81	3.85	0.77	- 1.13	2.08	0.41

4.3.4.8 Approximants [l lʲ r rʲ n nʲ] in the Context of the Vowel [u].

These consonants were recognized very well. The plain liquid consonants /r/ and /l/ were identified with an accuracy of 100% at the Identification Gate. The accuracy for their palatalized counterparts, /rʲ/ and /lʲ/, was also high at the same gate, 95% and 86%, respectively. Subjects were also accurate when they had to determine if a nasal consonant was plain (/n/, 91%) or palatalized (/nʲ/, 68%). Figures 4.25 (a), (b), (c), (d), (e) and (f) show confidence rankings for all consonants across all gates. Russian subjects' accuracy was mirrored in the confidence of their ratings. According to the boxplots, the first significant rise in confidence occurs at the Identification Gate. The highest level of confidence is displayed at the Recognition Gate.

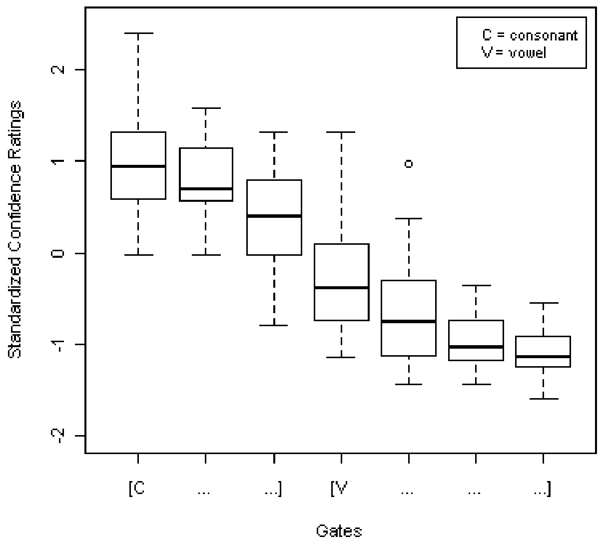


Figure 4.25.a. Boxplots of Confidence Rankings of all gates of Russian [luk], Audio-Visual Condition

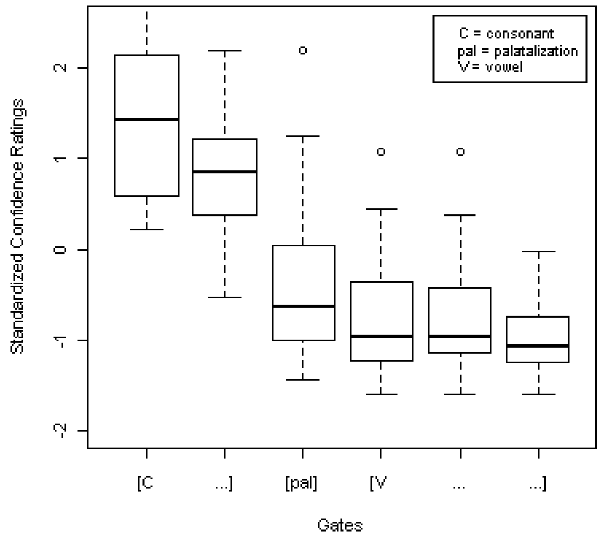


Figure 4.25.b. Boxplots of Confidence Rankings of all gates of Russian [lʲuk], Audio-Visual Condition

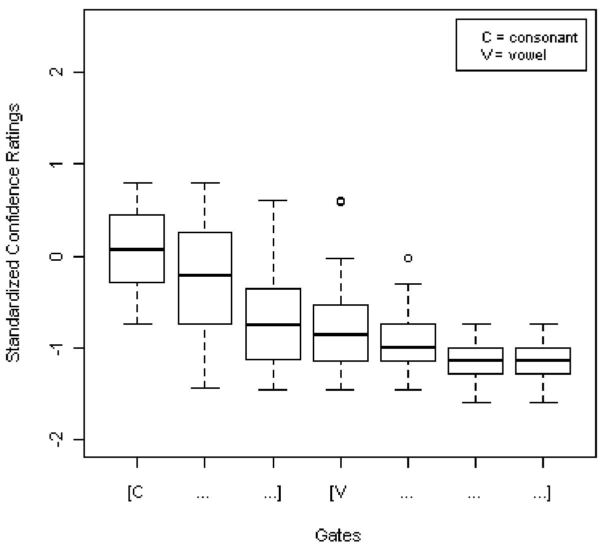


Figure 4.25.c. Boxplots of Confidence Rankings of all gates of Russian [rumba], Audio-Visual Condition

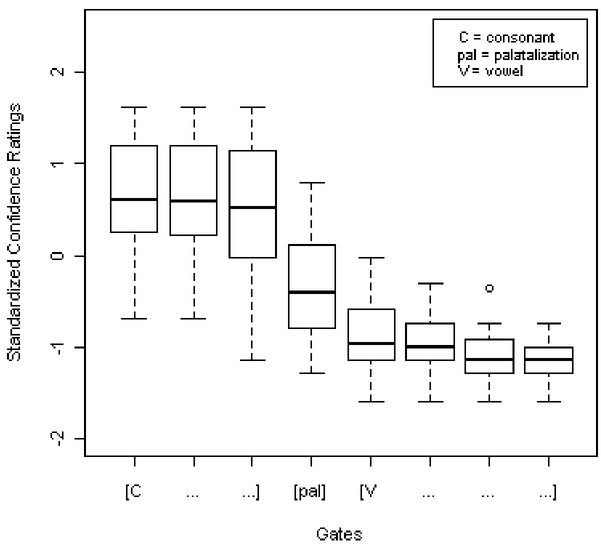


Figure 4.25.d. Boxplots of Confidence Rankings of all gates of Russian [rʲumka], Audio-Visual Condition

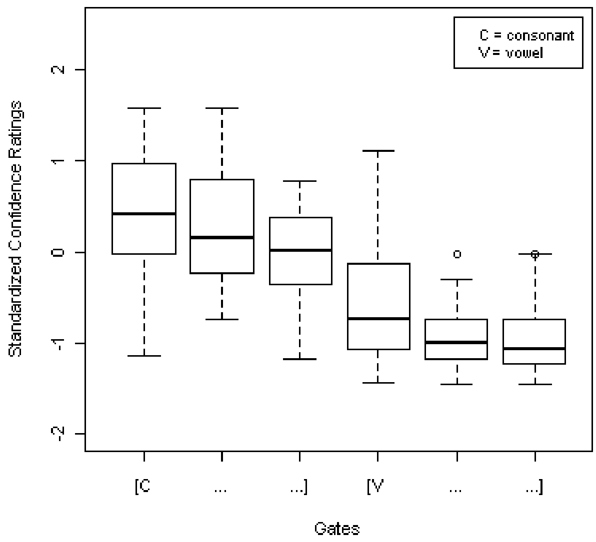


Figure 4.25.e. Boxplots of Confidence Rankings of all gates of Russian [nuga], Audio-Visual Condition

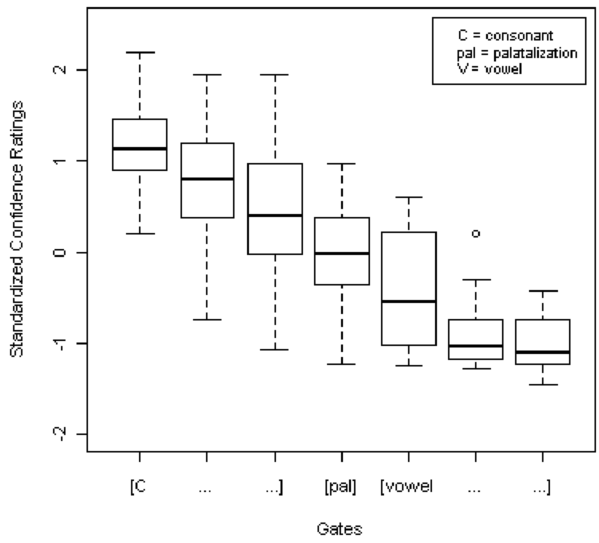


Figure 4.25.f. Boxplots of Confidence Rankings of all gates of Russian [nʲux], Audio-Visual Condition

One-Way Repeated Measures ANOVAs established a main effect of Gate for each consonant, Table 4.24. The Greenhouse-Geisser corrections to departure from sphericity were applied, as the sphericity condition was violated in all cases.

Table 4.24 Repeated Measures ANOVA of Confidence Ratings for Approximants, [u] Context, Audio-Visual Condition, Russian subjects.

Factor	df	F	Pr(>F)	Sphericity Test	Pr(>F[GG])
/l/ Gates	2, 42	80	< 0.001 ***	p = 0.26711	< 0.001 ***
/lʲ/ Gates	2, 42	66	< 0.001 ***	p = 0.077975	< 0.001 ***
/r/ Gates	2, 42	44	< 0.001 ***	p = 0.78971	< 0.001 ***
/rʲ/ Gates	2, 42	43	< 0.001 ***	p = 0.14751	< 0.001 ***
/n/ Gates	2, 42	33	< 0.001 ***	p = 0.1312	< 0.001 ***
/nʲ/ Gates	2, 42	126	< 0.001 ***	p = 0.014242	< 0.001 ***

'R' Significance Codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Following the ANOVAs, pairwise comparisons between the critical gates of the consonants were conducted to find out if the mean differences (Table 4.25.) were significant. T-tests indicated that subjects were more confident at the Isolation Gate, compared to the Initial Gate: /l/, $F(2,42) = 80$, $p < 0.001$; /lʲ/, $F(2,42) = 66$, $p < 0.001$; /r/, $F(2,42) = 44$, $p < 0.001$; /rʲ/, $F(2,42) = 43$, $p < 0.001$; /n/, $F(2,42) = 33$, $p < 0.001$; /nʲ/, F(2,42) = 126, $p < 0.001$. Moreover, in terms of the standardized rating scale, confidence level either approached (/l/, - 0.28; /lʲ/, - 0.24; /rʲ/, - 0.34; /nʲ/, - 0.07) or exceeded (/r/, - 0.73; /n/, - 0. 55) 'fairly sure' (0.4). Russian subjects were most confident at the Recognition Gate: /l/, $p < 0.001$; /lʲ/, p = 0.0021; /r/, p = 0.022; /rʲ/, p = 0.0027; /n/, $p < 0.001$; /nʲ/, $p < 0.001$.

Table 4.25 Confidence Ratings (in z-scores) for Approximants, [u] Context, Audio-Visual Condition, Russian Subjects

		Initial Gate			Isolation Gate (1)			Recognition Gate		
Consonant	**N**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**	**Mean**	**Range**	**SD**
/l/	22	1.04	2.43	0.67	-0.28	2.47	0.70	-1.14	1.96	0.40
/lʲ/	22	1.38	2.52	0.79	-0.24	3.62	1.03	-1.00	1.57	0.38
/r/	22	0.06	1.54	0.45	-0.73	2.06	0.58	-1.18	1.76	0.38
/rʲ/	22	0.67	2.31	0.58	-0.34	2.07	0.63	-1.18	1.76	0.38
/n/	22	0.39	2.73	0.74	-0.55	2.54	0.63	-0.98	1.43	0.39
/nʲ/	22	1.18	1.98	0.50	-0.07	2.20	0.63	-1.02	1.03	0.28

4.3.4.9 Summary of Results – Approximants [l lʲ r rʲ n nʲ] in the Context of the Vowels [a] and [u].

Overall, this group of consonants was best identified on both of the dependent measures, accuracy and confidence rating. In the environment of the vowel /a/, the plain and palatalized nasal consonants were recognized with the least response accuracy (64%), compared to the rest of the consonants. Moreover, subjects were 'fairly unsure' in their responses. In the environment of the vowel /u/, the accuracy improved for both nasal consonants. So did subjects' ratings for the confidence measure. The performance for the liquid consonants, plain and palatalized, was very good, on both dependent measures and in both vowel contexts. The response accuracy was at least 86% at the Isolation Gate. At the Recognition Gate, the performance accuracy for all of the consonants, in both vowel contexts, was flawless – 100%.

Chapter 5

The Phonological Representations of Bulgarian Palatalized Consonants

5.1 Introduction

Based on phonetic evidence from a cross-language comparison of three languages – Bulgarian, Russian and Southern British English, we can be certain that Standard Bulgarian still has palatalized consonants. However, the phonetic similarities (acoustic and perceptual) of Bulgarian and Russian palatalized consonants do not necessarily imply identical phonological representations of these consonants in the respective languages. Even within the same language, segments which share similar phonetic features may have different phonological behaviours. For example, Davis and Hammond (1995) have shown that in American English the labial glide /w/ syllabifies with the onset consonants while the palatal glide /j/ is part of the nucleus, together with the vowel /u/. Their analyses are justified on the different phonotactics of consonant-labial glide-vowel and consonant-palatal glide-vowel sequences. The palatalized consonants of Bulgarian and Russian vary significantly in their surface distribution. In what follows, we will exemplify these differences. I will then argue that the phonological representations of Bulgarian soft consonants consist of a sequence of /CjV/.

5.2 Distribution of Bulgarian and Russian Palatalized Consonants

Russian palatalized consonants can occur next to each of the five vowels of the language, [i, e, a, u, o]. Furthermore, they can appear in the following environments:

(a) Word/Syllable-Initially: [bʲit], ‘beaten’; [tʲma], ‘darkness’; [vʲet.ka], ‘branch’; [vʲol], ‘he led’; [lʲuk], ‘hatch’; [mjat], ‘crumpled’;

(b) Word/Syllable-Finally: [gonʲ.ba], ‘chase’; [sʲestʲ], ‘to sit down’; [krofʲ], ‘blood’;

As the examples above illustrate, Russian palatalized consonants can occur in the margins of syllables and words, or they can be the initial consonant of a CC cluster (eg., [tʲma]). They can also be found in medial consonantal clusters, across syllables (c) or prepausally, within the phonological word (d):

(c) [ba**lʲ.nʲ**i.ʦa], ‘hospital’; [melʲ.nʲi. ʦa], ‘mill’; [na.ʧalʲ. nʲik], ‘boss’;

(d) [Igo**rʲ pʲ**il malako], ‘Igor drank milk’

In fact, Russian palatalized consonants can be found in all the environments where the plain consonants of the language appear as well. Most palatalized consonants have plain counterparts and engage in minimal, or near-minimal, contrasts as can be seen among the examples in (e, f, g). It is worth noting that contrastive palatalization can occur syllable-initially, syllable-finally, or word-medially, before another consonant:

(e) [**lʲ**uk], ‘hatch’; [**l**uk], ‘onions’;

(f) [kro**f**], ‘shelter’; [kro**fʲ**], ‘blood’

(g) [po**l.k**a], ‘shelf’; [po**lʲ.k**a], ‘polka’

In Russian, there is also a three-way contrast among [CV], [CʲV] and [CʲjV] segmental sequences, for example, [ˈdatelʲ], ‘giver’; [ˈdʲatel], ‘woodpecker’; [ˈdʲjak], ‘clark’.

Bulgarian palatalized consonants appear in very restricted environments, only syllable-initially, next to the vowels [a u ɔ] as the examples in (h). They can occur word-medially but only syllable-initially as the words in (i) indicate. Unlike Russian, Bulgarian does not tolerate **CʲC** clusters, either in the syllable onset, or prepausally. Only **CC** clusters are found in these environments, as the first word in (k) and the phonological words in (l), respectively. Consonant clusters of the **CCʲ** variety are possible only syllable-initially (k):

(h) [mʲa.tam], ‘I wave’; [gʲɔl], ‘puddle’; [tʲul], ‘tulle’; [vʲa.tɤr], ‘wind’;

(i) [lʲul.lʲak], ‘lilac’; [dʲu.lʲa], ‘quince’; [na.rʲa.zan], ‘cut up’;

(k) [**sv**at], ‘relative by marriage’; [**svʲ**at], ‘world’; [za.**klʲ**u.ʧɛn], ‘locked up’;

(l) [**s** ˈ**v**a.ta], ‘with interlining (for clothes)’; **[s** ˈ**vʲ**a.tɤr], ‘with wind’

As in Russian, most Bulgarian palatalized consonants have plain counterparts. Unlike Russian, Bulgarian contrastive palatalization occurs only syllable-initially:

(m) [**m**ar.ka], ‘stamp’; [**mʲ**ar.ka], ‘measure’; [**l**uk], ‘onions’; [**lʲ**uk], ‘hatch’; [**g**ol], ‘naked’; [**gʲ**ol], ‘puddle’.

In summary, Russian palatalized consonants appear in all environments where plain consonants can be found: next to all vowels of the language ([i, e, a, u, o]), in syllable onsets and codas, in consonantal clusters, syllable-initial (CʲC, CCʲ) or syllable-medial (Cʲ.C, C.Cʲ, Cʲ.Cʲ). Bulgarian palatalized consonants appear in very restricted environments: only in syllable onsets, before the vowels [a u ɔ].

5.3 Phonological Representations of Bulgarian Palatalized Consonants

Experimental evidence from the acoustic and perception studies points to similarities in the phonetic shape of the palatalized consonants of Bulgarian and Russian. However, we have seen that the phonetic distribution of these segments is very different in the respective languages. In fact, in terms of their surface distribution, Bulgarian C^jV sequences pattern with the CjV sequences of British English. I will make an argument against a one-to-one mapping between the phonetic and phonological representations of the Bulgarian palatalized consonants. Instead, I propose that at the level of phonology they consist of a sequence of /CjV/.

There are two additional pieces of evidence that compel us to assume that, underlyingly, Bulgarian [C^jV] sequences are represented as /CjV/. The language has contrastive minimal, or near minimal segmental C#jV/ C#V sequences, as can be seen in the examples in (n). These sequences consist of a preposition, followed by a word stem. In connected speech, the stem glide /j/ will palatalize the consonant on the surface. More importantly, when the sequence is syllabified, the coda consonant /d/ of the preposition will become the onset consonant in line with onset maximization. The words in (p) are near-minimal pairs of their respective C#jV/ C#V sequences. They will syllabify in the same way, only the palatalized consonant will be in onset position. Thus, the syllabification of minimal pairs such as [prɛ**d ja.**v^{j}a.va.nɛ] and [prɛ.**d^{j}a**.v^{j}a.vam] provide further evidence for the underlying [Cj] shape of Bulgarian palatalized consonants.

(n) [prɛ**d ja.**v^{j}a.va.nɛ], 'prior to appearing; [prɛ**d a.**va.rɪ.ja], 'close to breaking down'

[**s** ˈ**a**n.ka], 'with Anka'; [**s** ˈ**ja**n.ka], 'with Janka'

(p) [prɛ.**dʲa**.vʲa.vam], ‘lay claim to’; [prɛ.**da**.va.tel], ‘trasmitter’

[ˈ**sa**n.ktsɪ.ja], ‘sanction’; [ˈ**sʲa**n.ka], ‘shaddow’

Another piece of empirical evidence that points to the /CjV/ phonological shape of Bulgarian palatalized consonants comes from the so called ‘stem /j/’, *‘Conjugation-I’* verbs in Table 5.1. This stem is part of the traditional ‘multi-stem’ classification of Bulgarian verb types (Stojanov, 1964). The bold endings, following the palatal glide /j/, are ‘person’ and ‘number’ morphemes. For the moment, it is important to notice that the **/ja/** sequences are in syllable-initial position.

Table 5.1 Examples of /j/-stems in the Present and Aorist Tenses

‘charm’	Present	Aorist	‘sow’	Present	Aorist
sg. 1	ba.j**a**	ba.j**ax**	sg. 1	se.j**a**	sj**ax**
sg. 2	ba.**eʃ**	ba.j**a**	sg. 2	se.**eʃ**	sj**a**
pl. 3	ba.j**at**	ba.j**a**.**xa**	pl. 3	se.j**at**	sj**a**.**xa**

In Table 5.2 we have some more examples, this time from *‘Conjugation-II’* verbs[7]. Traditional grammarians have not isolated a satisfactory stem type for verbs like ‘sit’ and ‘tolerate’[8]. They share the same morphemes for ‘person’ and ‘number’ with the forms in Table 5.1 but differ from them, at least on the surface, in that their stems end in a palatalized consonant instead the palatal glide. Note again that, once the ‘person’ and ‘number’ morphemes join the verb stem, the palatalized consonant is in the onset of the second syllable.

[7] The ‘Conjugation’ type merely reflects the /i/ or /e/ vowel morpheme in the second person, singular, which is not important for our current analyses.
[8] ‘Conjugation-III’ verbs with a vowel morpheme /a/ in the second person, singular, have verbs with a similar type of stem.

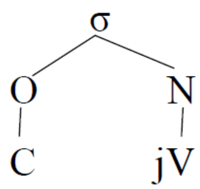
Table 5.2 Further Examples of Conjugated Verbs in the Present and Aorist Tenses

‘sit’	Present	Aorist	‘tolerate’	Present	Aorist
sg. 1	sɛ.dʲ**a**	sɛ.dʲ**ax**	sg. 1	tɤr.pʲ**a**	tɤr.pʲ**ax**
sg. 2	sɛ.d**ɪʃ**	sɛ.dʲ**a**	sg. 2	tɤr.p**ɪʃ**	tɤr.pʲ**a**
pl. 3	sɛ.dʲ**at**	sɛ.dʲ**a.xa**	pl. 3	tɤr.pʲ**at**	tɤr.pʲ**a.xa**

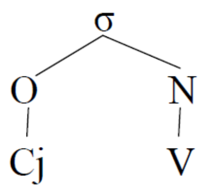
As we mentioned before, the ‘multi-stem’ classification system of Bulgarian verb types (Stojanov, 1964) has difficulty proposing a stem type for the verbs in Table 5.2. The problem is that in the onset position of the second syllable we can have a variety of palatalized consonants on the surface. If, however, we turn to the phonological representations of the stems in Table 5.2, on the assumption that palatalized consonants are analysed as /Cj/ sequences, then all verb forms can be classified as having /j/-stems.

Once we accept that the underlying shape of Bulgarian palatalized consonants is /Cj/, we must determine if the glide belongs to the onset of the syllable, as in (r), or to the nucleus of the syllable, as in (s).

(r)



(s)



Legend: σ = syllable; O = onset; N = neucleus

We will address this question with reference to the segmental organization of the syllable. Linguists have noted cross-linguistic tendencies in the ordering of segments in the syllable onset, nucleus and coda. It has been proposed that these segmental relations within the syllable are based on the Sonority Sequencing Principle (SSP) (Steriade, 1982; Selkrik, 1984; among others). Broadly defined the SSP states that the nucleus of the syllable is its most sonorous part and, as such, constitutes its peak; segments to the left (onset) or right (coda) of the syllable nucleus progressively degrease in sonority. Following Clements (1990), I make two assumptions: (1) sonority constraints apply at the level of phonology, specifically, at the level of initial syllabification; (2) sonority is a ‘multivalued feature’.

As Clements (1990) notes, the *relative sonority* of segments only indicates as to whether, or not, a syllable obeys the SSP. To evaluate the complexity of clusters within a syllable, Clements (1990) proposed the following universal sonority scale: O < N < L < G < V (O = obstruents; N = nasals; L = liquids; G = glides; V = vowels). One benefit of this scale is that it groups plosive and fricative consonants into one category, obstruents (O). This grouping avoids ‘sonority plateaus’ in languages which allow a fricative-plosive sequence in syllable onsets. Table 5.3 has examples of such clusters and other biconsonantal clusters which appear in Bulgarian syllable onsets.

Table 5.3 Biconsonantal Onset Clusters in Standard Bulgarian

	p	b	t	d	k	g	v	z	m	n	r	l
p											pr	pl
b											br	bl
t												
d							dv			dn	dr	dl
k							kv		km	kn	kr	kl
g									gm	gn	gr	gl
f												
v					vk			vz	vm	vn	vr	vl
s	sp	sb	st	sd	sk	sg	sv		sm	sn	sr	sl
z				zd			zv		zm	zn	zr	zl
ʃ			ʃt		ʃk					ʃn	ʃr	ʃl
ʒ											ʒr	ʒl
ʧ												ʧl
ʦ							ʦv					
m										mn	mr	ml
n											nr	

As can be seen from Table 5.3, Bulgarian allows a wide variety of clusters in syllable onsets: OO, NN, ON, NL, OL. In Table 5.4, these clusters are grouped according to their Minimal Sonority Distance (MSD), based on Clements' (1995) sonority scale. The MSD of the segments in these clusters is considered from the onset to the neucleus of the syllable.

Table. 5.4 Minimal Sonority Distance (MSD) of Biconsonantal Complex Onsets in Bulgarian (adapted from Clements, 1990).

MSD = 0		MSD = 1		MSD = 2
OO	NN	ON	NL	OL
sp, sb, st, sd, sk, sg, sv, zd, zv, vk, vz, ʃk, ʦv	mn	km, kn, gm, gn, dn, sn, sm, zm, zn, vn, vm, ʃn	mr, nr, ml	pl, pr, bl, br, dl, dr, kl, kr, gl, gr, vl, vr, sl, sr, zl, zr, ʃl, ʃr, ʒl, ʒr, ʧl

It is immediately obvious that the language tolerates clusters with flat sonority (0), the majority of the clusters consist of consonants with a MSD of 1 or 2, which indicates rising sonority. Of particular interest to us are the clusters consisting of two sonorant consonants. Although /mn, mr, ml, nr/ are found in Bulgarian, they occur in a handful of words. Moreover, the language avoids two sonorants in the onset of syllables as confirmed by the prohibition of the following clusters [*nl, *nm, *rm, *rn, *rl, *lr, *ln, *lm]. In line with Davis and Hammond (1995), I take this as evidence that a /CjV/ will be syllabified as in (s). That is, the palatal glide /j/ will be parsed in the nucleus of the syllable, together with the vowel.

5.4 Conclusion

On the basis of distributional evidence and ‘j-stems’ from traditional ‘multi-stem’ classification system, I have argued that Bulgarian palatalized consonants have an underlying phonological representation of /Cj/. I then appealed to principles of segmental organization within the syllable, the Sonority Sequencing Principle and the Minimal Distance Sonority Principle (Steriade, 1982; Selkrik, 1984; Clements, 1990), to show that the underlying palatal glide is parsed into the nucleus of the syllable, as in (s).

Chapter 6

General Discussion and Conclusion

6.1 On the existence of palatalized consonants in Standard Bulgarian.

The main goal of this dissertation was to establish if palatalized consonants are still present in Standard Bulgarian. These consonants have a limited distribution in the language as they appear only in syllable onsets before the back vowels [u], [a] and [ɔ]. Despite the fact that they are found in restricted environments, some form of plain-palatalized consonantal contrast is still maintained in the language. In simple terms, the research question is whether this contrast is signalled by [C^j] or [Cj]. Thus, the first two sounds of [*du*nav] ('the Danube') will contrast either with [*d^ju*nə] or [*dju*nə] ('dune'). Embedded in our research methodology are cross language comparisons. Accordingly, if depalatalization has taken place, as Horálek (1950) claimed, the Bulgarian palatalized segmental sequence could be identical to the British English [*dju*nə], 'dune'. Alternatively, it could be similar to the Russian [*d^ju*nə] ('dune'), which would allow us to reject the *depalatalization* hypothesis.

Acoustically, palatalization is characterised by the rise of the F2 formant frequencies due to the narrowing in the frontal cavity caused by a high tongue position as for the high front vowel [i]. Conversely, there is no such rise in the F2 formant frequencies of the plain counterpart of palatalized consonants. The acoustic study employed Smoothing Spline ANOVAs (SSANVOVA) (Gu, 2002) to find out if there are any differences in the F2 formant trajectories of the plain an palatalized consonant-vowel sequences of Bulgarian, Russian and British English. We can be certain that the SSANOVA is a reliable measure of an existing plain-palatalized contrast. Recall that, when the contrast has been lost, the F2 formant contours overlap. Such was the case for ‘look’ and ‘Luke’ in British English. As expected, all three languages maintain the plain-palatalized contrast in the environment of the vowel [u]. Figures 5.1 a – c are typical examples of Smoothing Spline ANOVA graphs which compare the F1, F2 and F3 formant frequencies of plain-palatalized consonant vowel sequences. As can be seen from the graphs, the F2 formant contours are separated for a period of 0.12 seconds for Bulgarian and Russian (Figures 6.1a and b), and 0.20 seconds for British English (Figure 6.1c).

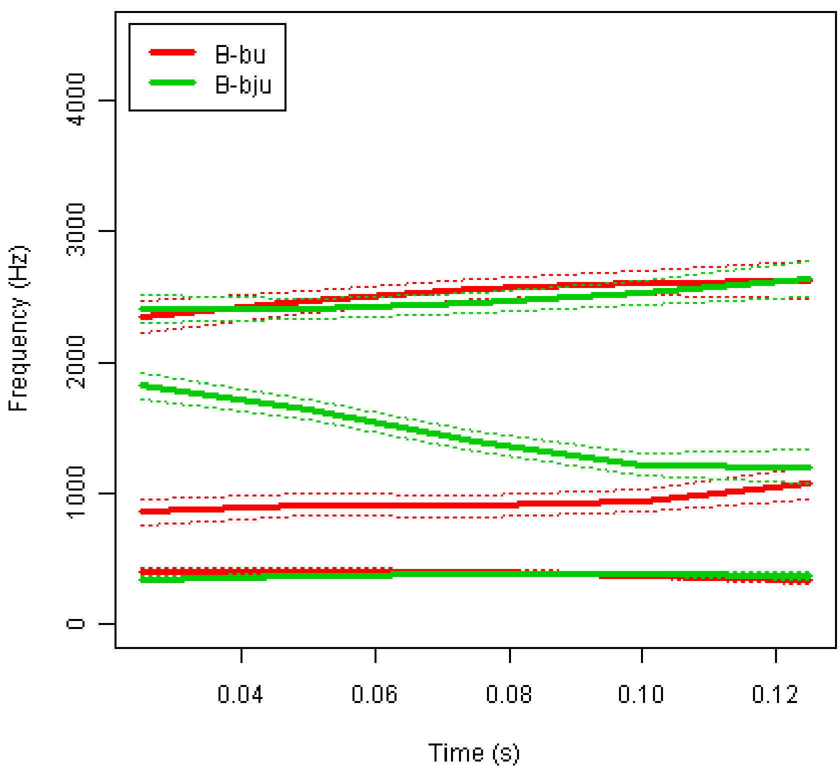


Figure 6.1a SSANOVA graph for [bu] & [bʲu], Bulgarian

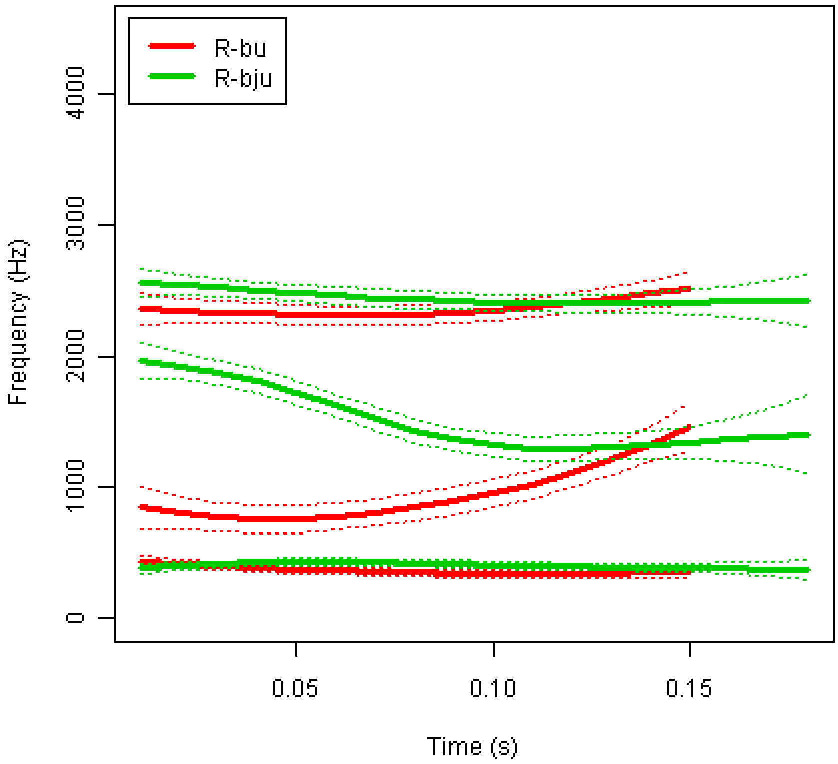


Figure 6.1b SSANOVA graph for [bu] & [bʲu], Russian

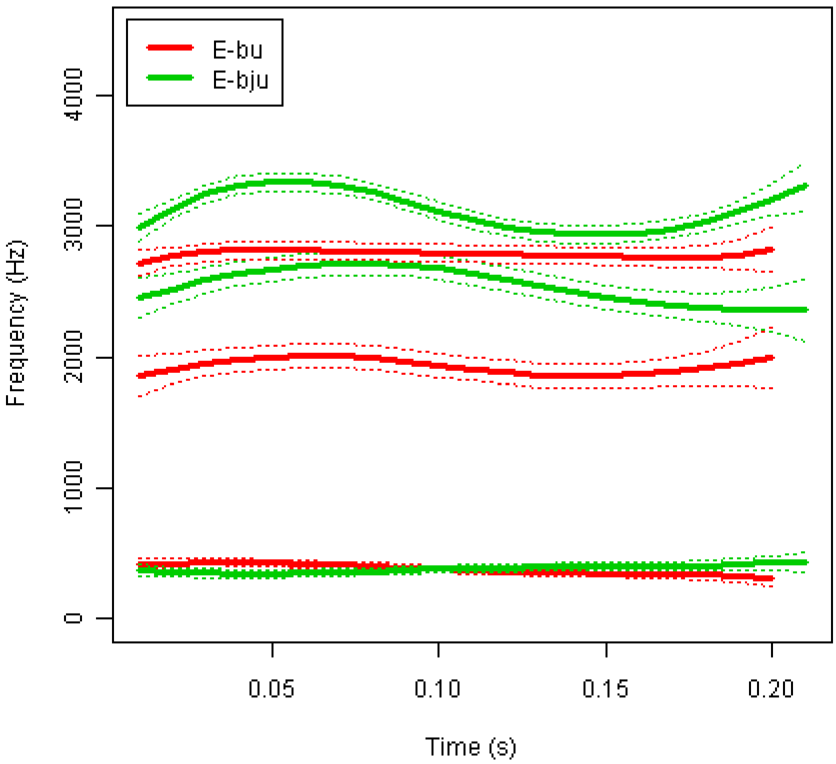


Figure 6.1c SSANOVA graph for [bu] & [bju], British English

In terms of the SSANOVA statistics, the Bulgarian plain-palatalized contrastive sequences are identical to the Russian ones and different from those of British English. This is true of all investigated consonants as can be seen in Table 6.1 which displays the average duration of contrast maintenance in all three languages. Moreover, the Bulgarian and Russian contrasts have similar durations in both vowel contexts, [a] and [u][9].

Table 6.1. SSANOVA Contrast Duration Averages

Consonants	Vowel [u] Context			Vowel [a] Context	
	British English	Bulgarian	Russian	Bulgarian	Russian
p, voiceless plosive	0.17s	0.12s	0.10s	0.12s	-
b, voiced plosive	0.14s	0.10s	0.10s	0.13s	-
t/k, voiceless plosives	0.15	0.10s	0.10s	0.12s	0.12s
d/g, voiced plosives	0.17s	0.11s	0.11s	0.12s	0.13s
f/s, voiceless fricatives	0.15	0.08s	0.08s	0.08s	0.08s
v/z, voiced fricatives	0.23s	0.10s	0.10s	0.10s	0.10s
m/n, nasals	0.15s	0.08s	0.08s	0.10s	0.10s
l lateral approximant	contrast lost	0.05s	0.05s	0.12s	0.13s
r trill	NA	0.07s	0.08s	0.08s	0.11s

We used an additional measure to establish another acoustic similarity between Bulgarian and Russian palatalized consonants. As the tongue is not involved in the primary articulation of labial palatalized consonants, any steady state formants post consonantal release can be associated with the palatal glide, irrespective of whether it is a primary or secondary gesture. According to this measure, the Bulgarian palatal element is identical to that of Russian but different from the one of British English. For example, in the [b_u] environment, we obtained 0.08 seconds for British English and 0.04 seconds

9 There is no data for the Russian p^ja and b^ja sequences as the F2 contours did not overlap.

for Bulgarian and Russian. The same duration (0.04 seconds) of the Bulgarian and Russian palatal element was measured in the [b_a] context. Thus, on the grounds of two dependent measures, the SSANOVA graphs and the duration of the steady state of the palatal element, we can reject the depalatalization hypothesis.

Bulgarian and Russian palatalized consonants were further compared in an audio-only perception experiment. Only the plain [t d s z l r n] consonants and their palatalized [t^j d^j s^j z^j l^j r^j n^j] counterparts were investigated as a Bulgarian x-ray study by Stojkov (1942, 1961) found an identical tongue body height in their articulation. The latter articulation parameter could cast a doubt on the existence of palatalized consonants in Standard Bulgarian. The gating methodology (Grosjean 1980, 1996) allowed us to find out how much perceptual information was needed by Bulgarian and Russian listeners to identify a consonant as palatalized. In a forced-choice task, subjects heard the palatalized consonant-vowel sequences over a number of gates. Each consecutive gate contained the auditory information from all previous gates. After listening to each gate, subjects chose one of the available alternative options and, then, rated how confident they were in their response.

Bulgarian and Russian listeners identified a palatalized consonant correctly on the basis of cues contained in the palatalized portion of the consonant. Thus, the cues found after the release of the consonant but prior to the transitions with the following vowel emerged as the Isolation Point, defined as the size of segment needed to identify a stimulus correctly (Grosjean, 1980; 1982). For both language groups, the accuracy of their responses is at least 95%. Furthermore, subjects rated their confidence at least –0.04 (fairly sure), but often approaching –1(very sure) on the standardized rating scale. This high level of confidence is often unexpected at the Isolation Point as they have heard a word only partially. Moreover, compared to the Isolation Point, the change of confidence level at the Recognition Point (the last gate of the presented sound sequence which contains the last portion of the vowel) is not statistically significant for most consonants. Importantly, there is only a 5% increase in the precision of subjects' responses. This means that the Bulgarian and Russian listeners can reliable use the cues of palatalization to identify a consonant as palatalized. The results from this study do not support Tilkov's findings that the transitions with the following vowel are necessary to perceive a consonant in Standard Bulgarian as palatalized.

The audio-only perception experiment also bears on the issue of depalatalization. For both languages, there are at most two [pal] gates. If the Bulgarian palatal element was a primary articulation, as in British English, there would be likely more than two [pal] gates on the grounds of the two durational measures from the acoustic study. According to the SSANOVA statistics, British English maintains the plain-palatalized contrast for a longer time, compared to Bulgarian and Russian. In addition, the duration of the steady state of the palatal glide is, on average, 0.04 seconds in Bulgarian and Russian and, at least, twice as long in British English (0.08 seconds). Thus, the depalatalization hypothesis can be rejected on the grounds of the gating methodology in the current perception experiment.

The acoustic and perception experiments point to identical phonetic shape of Bulgarian and Russian palatalized consonants. However, this does not imply monotonic phonological representations. Based on distributional evidence, I argued that Bulgarian palatalized consonants [C^j] consist of /Cj/ at the level of phonology. Appealing to the *Sonority Sequence Principle* (Steriade, 1982; Selkrik, 1984; among others) and Clements' *Universal Sonority Scale* (1990), I argued that the /j/ is parsed in the nucleus of the syllable.

In conclusion, we can be confident that palatalized consonants are still present in Standard Bulgarian. The results of the acoustic and perception studies should be taken into consideration in constructing methodologies for teaching young children how to read palatalized consonants. Ignateva-Tsoneva (2008) urged teachers to modify their teaching techniques as, in her opinion, these consonants did not exist in the language. However, her concerns are unfounded. Scholars should refer to sound experimental evidence before implementing dramatic changes in educational procedures. As research on Bulgarian palatalization is sparse, it is hoped that the studies in this dissertation will contribute to such issues.

6.2 Audio-Visual Gating Study: Results and Methodological Issues.

In terms of lip-gestures, palatalization is characterized by the spreading of the lips in the manner of the vowel [i]. It was expected that these visual cues would available to the subjects of the audio-visual experiment before the auditory cues, as indicated by previous research (Smeele, 1994; Cathiard et al., 1995). By this hypothesis, and in comparison to the audio-only gating study, it was expected that the Isolation Point for palatalized consonants would shift to an earlier gate. This was not the case as the gating procedure turned out to degrade the visual information. In retrospect, it seems previous audio-visual gating studies (Smeele, 1994; De La Vaux & Massaro, 2004; Jesse & Massaro, 2010) did not detail their results with respect to individual consonants for this reason. All three studies summarized their results in terms of visual features transmitted by the visual modality. For instance, Jesse & Massaro (2010) used the following feature classification scheme for consonants: voicing, nasality, place, frication, duration, rounding, and continuant.

Undoubtedly, the results from the current audio-visual study could have been best explained in terms of a similar feature specification scheme as certain consonants were perceived better than other. However, in the interest of transparency in research, chapter 4 reported how Bulgarian and Russian subjects performed on individual consonants. Overall, the Russian results were better than the Bulgarian. As there were inconsistencies within languages, it is not possible to attribute the uneven results to intelligibility issues pertaining to the Bulgarian or Russian speaker (Krikos & Lesner, 1982). There are other confounds and we will take them up in turns.

So, how is the visual information in the gated stimuli degraded? When we perceive our physical environment, we are able to store brief mental representations of spatio-temporal structures. This brief storage capacity was first documented by Sperling (1960) who called it sensory memory. It was later referred to as iconic memory by Neisser (1967). Since then, the two terms have been used interchangeably. Early tests on how much information subjects retained from a briefly presented display of letters, for example, discovered retention of three to four items (Cattell, 1886; Wundt, 1912). However, they often reported they felt they had seen more items than they could report. In a classic study, Sperling (1962) used a novel methodology, the partial report, to tap into those intuitions. Subjects were still presented with the whole array of items but they were cued which row of items to report. For example, a high-pitched tone might cue the middle of three rows of letters. If the cues occurred after offset of the displays and the sampled subsets were random, then accurate reports meant that all the presented items had been stored. Sperling's (1962) ingenious methodology discovered an early, high-capacity (about 9 items) and fast-decaying (about 200ms) sensory system, which could be easily disrupted by competing stimuli. Sensory memory has been well researched and documented (Loftus, Duncan & Gehrig, 1992; Lu, Neuse, Madigan, Dosher, 2005; among others).

Sensory memory enables us to perceive movies, or video clips dynamically, as a series of objects and events changing in time and space. In the current audio-visual experiment, the early gates appeared as a flicker. Not only was there not enough information, but some time elapsed before the subjects could register their responses. Importantly, it is highly likely that the encoding of information was disrupted by the irrelevant noise. As mentioned before, subjects' responses improved at the same Isolation Point as for the audio-only condition due to an accumulation of visual information. However, not all consonants benefitted from the accumulated visual cue because the noise masker turned out to be a confound on two levels: 1) it reduced the perceptual cues of various consonants to a different degree; it increased the perceptual load and disrupted the processing of the available visual and auditory cues.

Unlike studies of auditory perception, audio-visual research has not addressed the impact of the noise masker on the perception of audio-visual stimuli. This is puzzling since we know that speech perception is multimodal (see Rosenblum, 2005, for an overview) and that we do not perceive the physical world as an environment without any interruptions. As Broersma and Scharenborg (2010) noted, different types of noise affect speech perception differently, even at the same SNR. Thus, speech-shaped noise, for example, hinders speech perception more than 'competing talker noise'. Phatak, Lovitt, and Allen (2008) showed that white noise impairs the perception of sounds more than speech-shaped noise and that individual sounds differed considerably in the extent to which perception decreased from one noise type to the other.

How, then, is the perception of the visual modality disrupted by white noise, for example. We know that subjects' performance accuracy in identifying consonants is very poor if only visual information is available to them. I believe that reduced auditory information for some of the consonants in the audio-visual condition of the current experiment will make their perception more like the perception of the same consonants in a visual-only condition. As the power spectrum for average speech has a roll-off of about – 8.7dB/octave above 500 Hz, the white noise masks the high frequencies in speech to a greater extent than low frequencies (Cos & Moore, 1988). Thus, it is not surprising that the performance for fricative consonants was the worst for both language groups in the current audio-visual experiment. Note also that one of perceptual cues for the secondary palatalization gesture is the high frequency noise caused by the constriction created by the raising of the tongue body towards the palate and the narrowing of the front cavity.

The white noise masker confounded the results in one more way. Recall that the sensory system is very fragile and could be easily disrupted by competing stimuli (Sperling, 1962; Loftus, Duncan & Gehrig, 1992). This could explain the uneven performance of nasal consonants, for example, within the same language. In theory, the lip-spreading gesture should be more pronounced in the context of the vowel [u] as the lip-rounding tends to be neutralized. However, within the Bulgarian group, the palatalized nasal consonant [n^j] was identified with an accuracy of 80% next to [a] and 65% next to [u].

The goal of the audio-visual perception study was to find out if Bulgarian and Russian listeners make use of visual cues associated with the secondary palatalization gesture. While the results of the study are inconclusive, it is hoped that future research will benefit from the methodological issues raised in this chapter.

6.3 Directions for future research

6.3.1 Audio-Visual Gating Perception Experiment

It is important to find out if the secondary palatal gesture is perceived from visual cues. We know that the gating methodology is appropriate for the audio but not for the visual modality. Therefore, in an audio-visual condition, only the auditory input can be gated while leaving the video input intact. The processing of visual information in the audio-visual condition can be assesses against two baseline conditions: auditory only, visual only. Furthermore, speech-shaped noise (SNR to be determined) could be added to an audio-visual file for a separate audio-visual condition. This condition can potentially simulate a more natural environment in which visual cues complement auditory information to aid the recognition of secondary palatal gestures.

6.3.2 Ultrasound Study

An ultrasound study is being planned. The purpose of this study is to investigate the articulatory dynamics of palatalized consonants in Bulgarian and Russian and to compare them across languages. Two factors are of particular interest: (1) the height of the tongue body (in relation to the hard palate) during the articulation of the secondary palatal gesture; (2) the timing of gestural overlap between the primary and secondary gesture. The Bulgarian (Stojkov, 1942; 1961) and Russian (Daniel & Ward, 1969) x-ray studies reveal articulatory differences between the palatalized consonants of the two languages (Appendix 1, page 199). In Bulgarian, the articulation of the secondary gesture does not involve a displacement of the tongue body towards the hard palate, as in Russian. This is surprising given the acoustic and perceptual similarities established through cross-language comparisons in this work.

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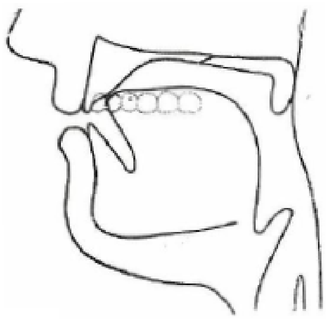
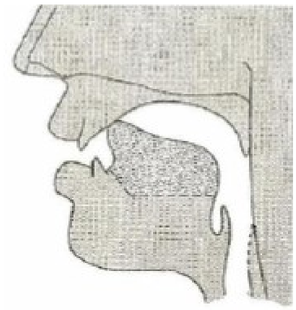
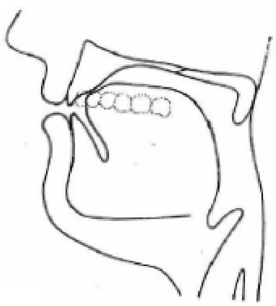
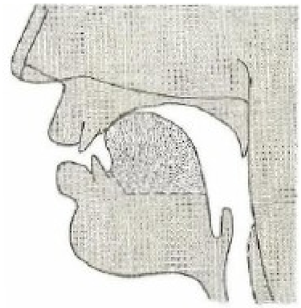
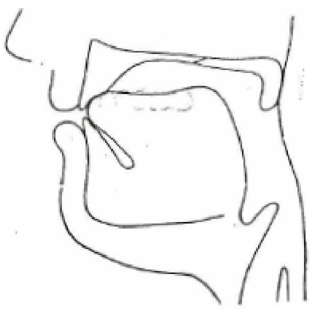
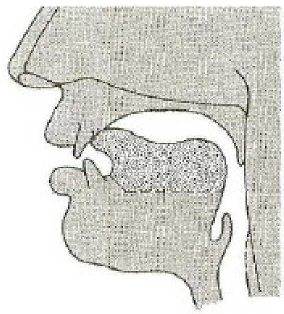
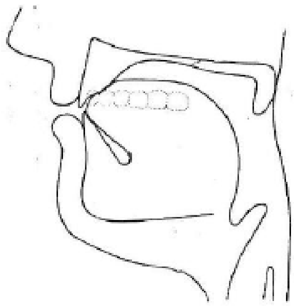
Appendix 1

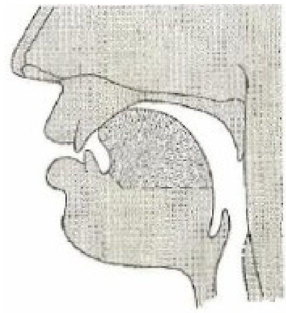
Comparison of Bulgarian and Russian Plain and Palatalized Consonants

Bulgarian	Russian
 [r] Обр. 112. Съгласна р	 [r] Fig. 30. Tongue-position for Russian r
 [r^j] Обр. 114. Съгласна р'	 [r^j] Fig. 31. Tongue-position for Russian ŗ
 [l] Обр. 106 Съгласна л	 [l] Fig. 28. Tongue-position for Russian l

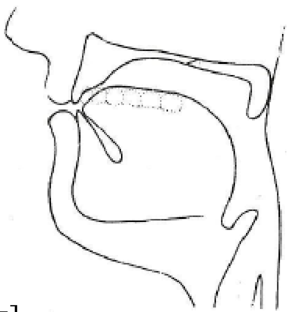
Bulgarian **Russian**



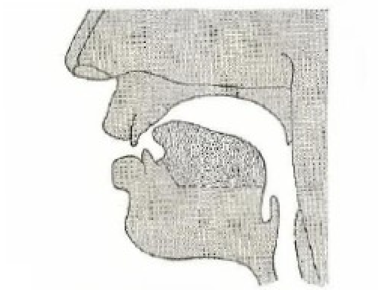
[lʲ] Обр. 109. Съгласна л'



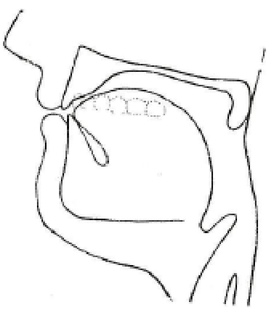
[lʲ] Fig. 29. Tongue-position for Russian ļ



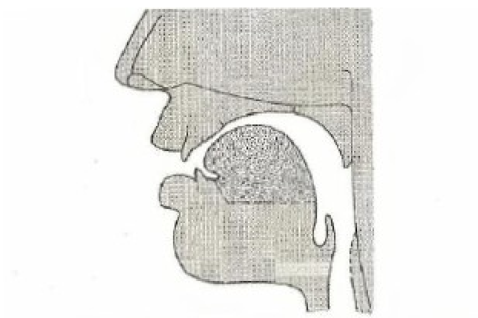
[s , z] Обр. 100. Съгласна с



[s , z] ... 17. Tongue-position of Russian s and z with tip of tongue in raised position



[s ^{j}, z^j] Обр. 102. Съгласна с'



[s ^{j}, z^j] Fig. 18. Tongue-position of Russian ș and ẓ with tongue-tip lowered

Bulgarian x-ray tracings (from Stojkov, 1961).

Russian x-ray tracings (from Daniel & Ward, 1969).

Appendix 2. Stimuli – Acoustic Study

Cu-C^{j}u/Cju Contrast					
Cons	**Bulgarian**	**Glossary**	**Russian**	**Glossary**	**British English**
/p^j/	/p^{j}ub/	nonce word	/p^{j}ub/	nonce word	puberty
/p/	/publika/	public	/pub.l^{j}i.ka/	public	Pooh Bear
/b^j/	/b^{j}ust/	bosom	/b^{j}ust/	bosom	beauty
/b/	/bus/	bus	/busɨ/	beads	boot
/f^j/	/f^{j}ur/	nonce word	/f^{j}ur/	nonce word	few
/f/	/furna/	oven	/fura/	wagon	fool
/v^j/	/v^{j}uk/	nonce word	/v^{j}uk/	nonce word	view
/v/	/vuk/	nonce word	/vuk/	nonce word	vook (nonce)
/t^j/	/t^{j}ul/	fine silk net	/t^{j}ul/	fine silk net	tulip
/t/	/tul/	sheepskin	/tula/	Tula, town	tool
/d^j/	/d^{j}una/	dune	/d^{j}una/	dune	dune
/d/	/dunav/	the Danube	/dunut^j/	to blow	doom
/s^j/	/s^{j}u/	Sue	/s^{j}u/	Sue	super
/s/	/supa/	soup	/sup/	soup	soup
/z^j/	/z^{j}us/	nonce word	/z^{j}us/	nonce word	Zeus
/z/	/zus/	nonce word	/zus/	nonce word	zoo
/l^j/	/l^{j}uk/	hatchway	/l^{j}uk/	hatchway	luke
/l/	/luk/	onion	/luk/	onion	look

/r^{j}/	/ru^{j}mka/	nonce word	/ru^{j}mka/	wine-glass	-------
/r/	/rum.ba/	rumba (dance)	/rum.ba/	rumba (dance)	-------
/m^{j}/	/m^{j}uzikɤl/	musicale	/m^{j}uz^{j}ikl/	musicale	muse
/m/	/muzika/	music	/muzɨka/	music	moose
/n^{j}/	/n^{j}ux/	intuition	/n^{j}ux/	intuition	new
/n/	/nux/	nonce-word	/nux/	nonce word	noon
/k^{j}/	/k^{j}up/	jar, pot	/k^{j}up/	nonce word	Cupid
/k/	/kup/	pile	/kup/	cube	coop
/g^{j}/	/g^{j}ul/	rose (old)	/g^{j}ul/	rose (old)	gue (a musical instrument, used in the early 1900)
/g/	/gul/	nonce word	/gul/	noise, buzz	ghoulish

Ca-C^{j}a/Cja Contrast				
Cons	**Bulgarian**	**Glossary**	**Russian**	**Glossary**
/p^j/	/p^{j}al/	He had sung.	/p^{j}alit^j/	to stare (infinitive);
/p/	/palka/	stick	/palka/	stick
/b^j/	/b^{j}as/	rage	/b^{j}as^j/	type of fabric
/b/	/baza/	base	/baza/	base
/f^j/	/f^{j}ar/	nonce-word	/f^{j}ar/	nonce-word
/f/	/far/	headlight	/fara/	headlight
/v^j/	/v^{j}al/	listless	/v^{j}a.la/	listless
/v/	/val/	bank (A raised shelf, etc.)	/val/	bank (A raised shelf, etc.)
/t^j/	/t^{j}as/	nonce-word	/t^{j}as/	nonce-word
/t/	/tas/	hips	/tas/	hips
/d^j/	/d^{j}al/	share, part	/d^{j}al/	nonce-word
/d/	/dal/	give, verb	/dal/	From '**дать', give**
/s^j/	/s^{j}akaʃ/	as if, as though	/s^{j}ak/	(in phrases)
/s/	/sak/	sack	/sak/	sack
/z^j/	/z^{j}apat/	stare, gaze (verb)	/z^{j}ap^j/	land
/z/	/zapat/	west	/zapat/	west
/l^j/	/l^{j}ava/	left	/l^{j}av/	math term – 'love'
/l/	/lava/	lava	/lava/	lava

$/r^j/$	$/r^j$adka/	rare	$/r^j$ad/	row, line
/r/	/radka/	Radka (Bulgarian name, feminine)	/rad/	glad
/m/	$/m^j$ata/	throw, cast	$/m^j$ata/	mint (herb)
/m/	/mat/	(check) mate	/mat/	(check) mate
/n/	$/n^j$am/	speechless	$/n^j$am/	yum (-yum)
/n/	/nam/	us (old)	/nam/	us
/k/	$/k^j$ar/	profit, gain	$/k^j$ar/	nonce-word
/k/	/kara/	drive (verb)	/kar/	nonce-word
$/g^j/$	$/g^j$as/	nonce-word	$/g^j$as/	nonce-word
/g/	/gas/	gas	/gas/	gas

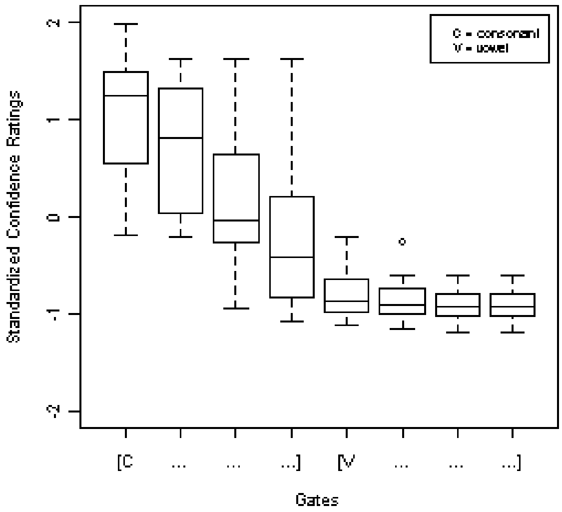
Appendix 3. Stimuli – Audio-Visual Gating Study

Ca-C^{j}a Contrast, Critical Stimuli				
Cons	**Bulgarian**	**Glossary**	**Russian**	**Glossary**
/v^j/	/v^{j}al/	‘blow’, v., 3p. sg., past tense	/v^{j}al/	‘withered; faded’, adj. masc., sg.
/v/	/val/	embankment’, n., masc., sg.	/val/	‘arbour’, n., masc., sg.
/t^j/	/t^{j}am/	‘to them’, pronoun	/tak/	‘so; thus’, adverb
/t/	/tam/	‘there’, place adverb	/t^{j}ak/	‘ draft; draught’, n., fem., pl., genitive case
/d^j/	/d^{j}ava/	‘put away’, v., 3p. sg., pres. tense	/d^{j}at^{j}el/	‘woodpecker’, n., masc., sg.
/d/	/dava/	‘give’, v., 3p. sg., pres. tense	/dat^{j}el^j/	‘giver’, n. masc., sg.
/s^j/	/s^{j}al/	'plant'., v., 3p., sg., masc., past tense	/s^{j}ad^j/	‘sit down’, v., sg., imperative
/s/	/sal/	‘raft’, n., masc., sg.	/sad/	‘garden’, n., masc., sg.
/z^j/	/z^{j}apat/	‘gaze’, v., 3p. pl., pres. tense	/z^{j}ab^j/	‘winter tillage’, n., fem., sg.,
/z/	/zapat/	‘west’, masc., sg.	/zapat/	‘west’, masc.
/l^j/	/l^{j}ava/	‘left’, adj., fem., sg.	/l^{j}apat^j/	‘blur out’, v, imperfective
/l/	/lava/	‘lava’, n., fem. sg.	/lapa/	‘paw’, n., fem., sg.
/r^j/	/r^{j}adka/	‘occasional’, adj., fem., sg.	/r^{j}ad/	‘rank’, n., masc., sg.
/r/	/radka/	Bulgarian female name	/rad/	‘I am glad’, phrase
/n^j/	/n^{j}am/	‘mute’, adj., masc., sg.	/n^{j}am/	‘yam’, n., masc., sg.
/n/	/nam/	'to us', pronoun, 3p. pl.	/nam/	‘us’, pron., pl.

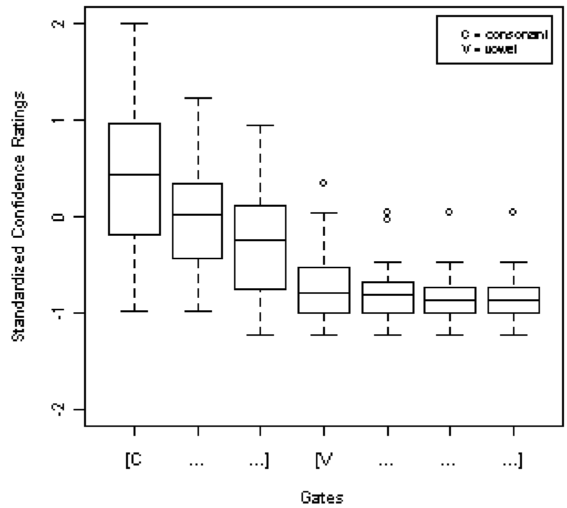
Cu-Cʲu Contrast, Critical Stimuli				
Cons	**Bulgarian**	**Glossary**	**Russian**	**Glossary**
/tʲ/	/tʲula/	'tulle net', n. masc., quantitative plural	/tʲuk/	'packet, n. masc. sg.,
/t/	/tula/	'sueded lambskin', n. fem. Sg.	/tuk/	'pomace', n. masc., sg,
/dʲ/	/dʲuna/	'dune', n., fem., sg.	/dʲuna/	'dune', n., fem. sg.,
/d/	/dunav/	The Danube	/dunutʲ/	'blow', v. infinit.
/sʲ/	/sʲu/	Female name	/sʲu/	Female name
/s/	/supa/	'soup', n., fem., sg.	/sup/	'soup', n. masc., sg.
/lʲ/	/lʲuk/	'hatch, hatchway', n., masc., sg.	/lʲuk/	'hatch, hatchway', n., masc., sg.
/l/	/luk/	'onion', n., masc., sg.,	/luk/	'onion', n., masc., sg.,
/rʲ/	/rʲup/	nonce word	/rʲumka/	'glass', n., fem., sg.
/r/	/rup/	nonce word	/rumba/	'rumba', n., fem., sg
/nʲ/	/nʲux/	'olfaction; scent; smell', n., masc.,	/nʲux/	'olfaction; scent; smell', n., masc.,
/n/	/nuga/	'nougat', n., fem., sg.	/nuga/	'nougat', n., fem., sg.

Fillers			
Bulgarian	**Glossary**	**Russian**	**Glossary**
/pile/	'chicken', n., neut. sg.	/pʲitʲ/	'drink', verb, infinitive
/bile/	'weed', n., neut., sg.	/bʲitʲ/	'beat', verb, infinitive
/tesen/	'narrow', n., masc., sg.	/tom/	'volume', n., fem., sg.
/desen/	'right', ajd., masc., sg.	/dom/	'house', n., fem., sg.
/sala/	'raft', n., masc., quantitative plural	/ʃalʲ/	'scarf', n., fem., sg.
/zala/	'hall', n., fem., sg.	/ʒalʲ/	'It's a shame', adverb
/kalen/	'muddy', adj., masc., sg.	/kostʲ/	'bone', n., fem., sg.
/galen/	'spoilt', adj., masc., sg.	/gostʲ/	'guest', n., masc., sg.
/faza/	'phase', n., fem., sg.	/faza/	'phase', n., fem., sg.
/vaza/	'vase', n., fem., sg.	/vaza/	'vase', n., fem., sg.
/noʃt/	'night', n., fem., sg.	/naʃa/	'our', pronoun, fem.. sg.
/moʃt/	'power', n., fem., sg.	/maʃa/	'Masha', female name
/veʃt/	'object', n., fem., sg.	/rʲetʃ/	'speech', n., fem., sg.
/peʃt/	'furnace', n., fem., sg.	/lʲetʃ/	'lie down', verb infinitive

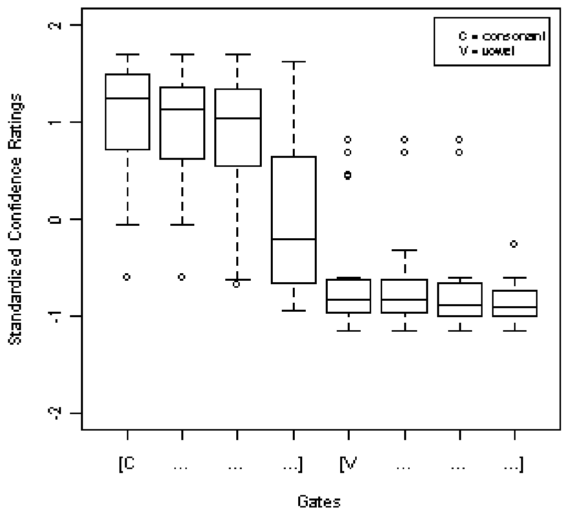
Appendix 4. Boxplots of the Words Containing the Approximants [l r n lʲ rʲ nʲ] in the Context of the Vowel [a], Audio-Only Condition.



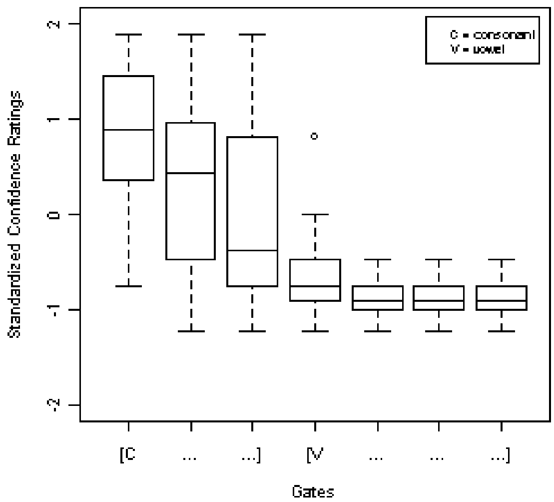
Boxplots of Confidence Rankings of all
gates of Bulgarian [lava], Audio Condition



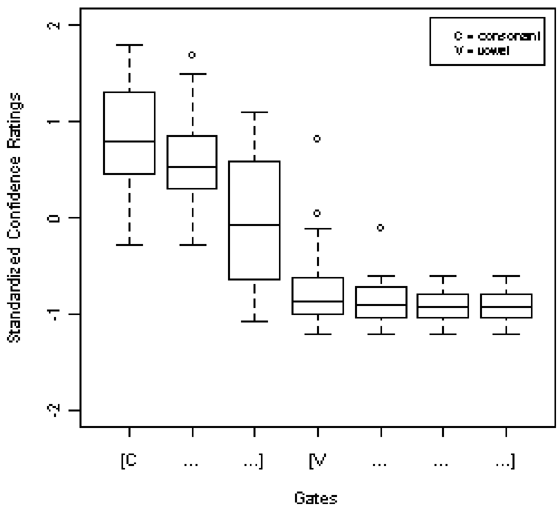
Boxplots of Confidence Rankings of all
gates of Russian [lapa], Audio Condition



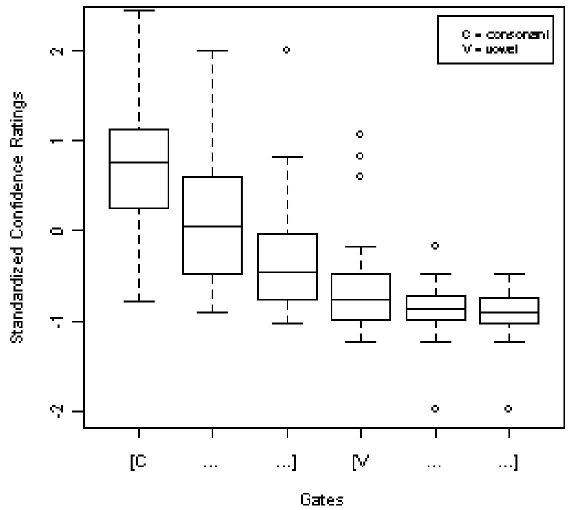
Boxplots of Confidence Rankings of all
gates of Bulgarian [nam], Audio Condition.



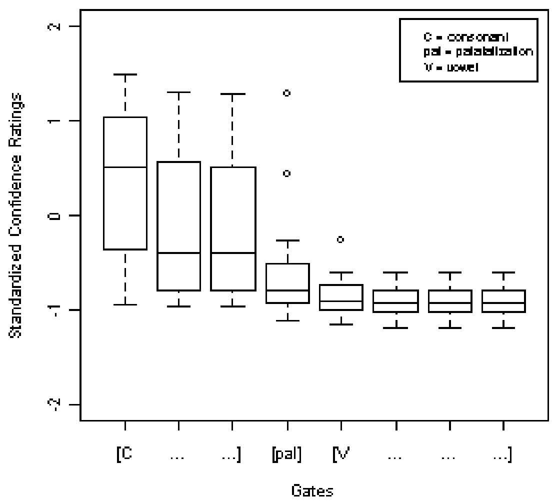
Boxplots of Confidence Rankings of all
gates of Russian [nam], Audio Condition



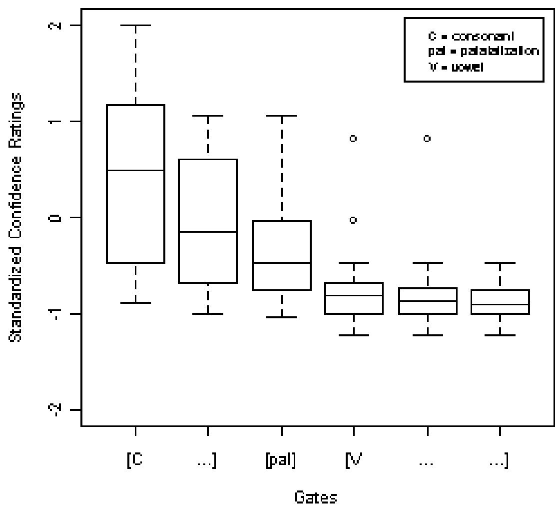
Boxplots of Confidence Rankings of all
gates of Bulgarian [radka], Audio Condition.



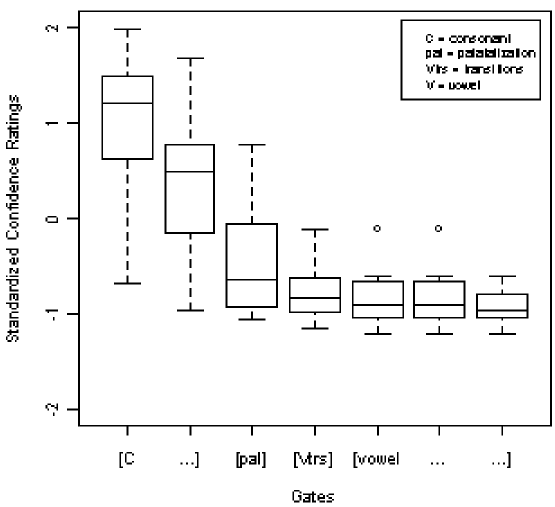
Boxplots of Confidence Rankings of all
gates of Russian [rad], Audio Condition



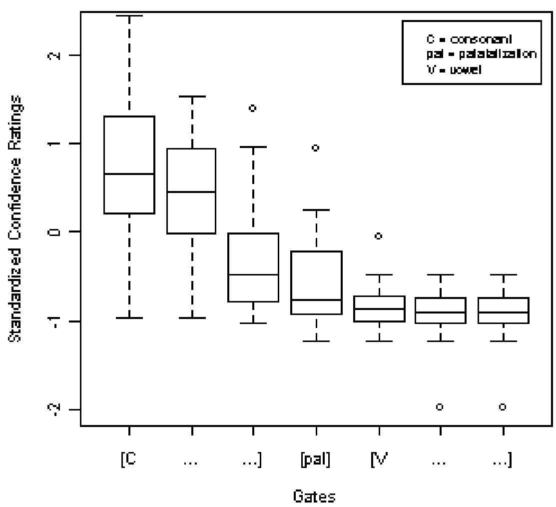
Boxplots of Confidence Rankings of all
gates of Bulgarian [l^java], Audio Condition.



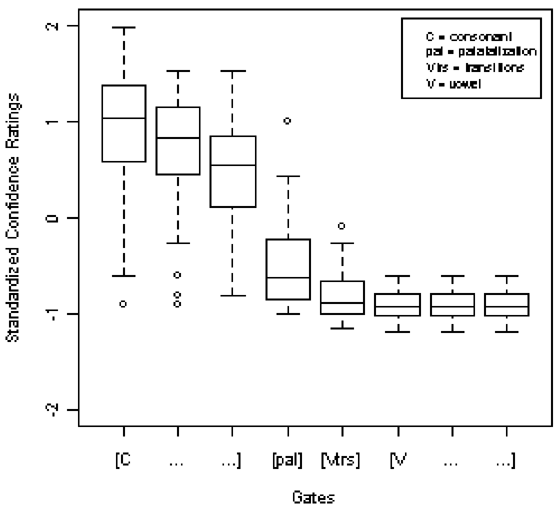
Boxplots of Confidence Rankings of all
gates of Russian [l^japat^j], Audio Condition



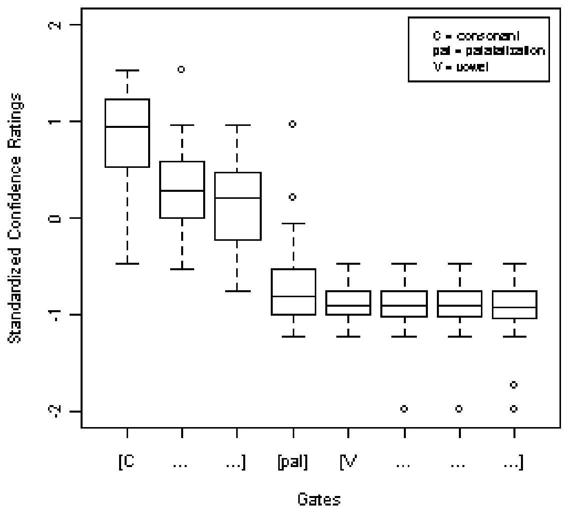
Boxplots of Confidence Rankings of all gates of Bulgarian [r^{j}adka], Audio Condition.



Boxplots of Confidence Rankings of all gates of Russian [r^{j}a], Audio Condition

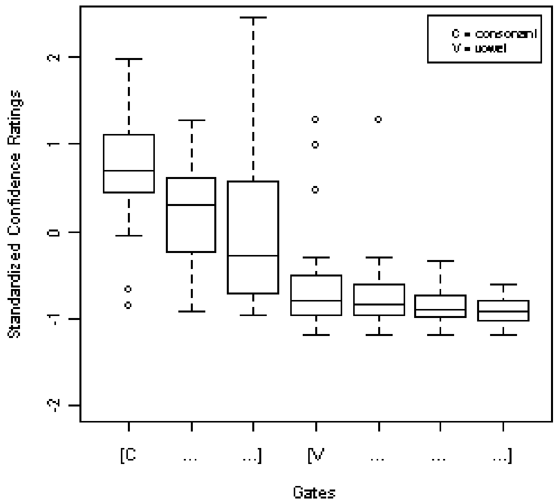


Boxplots of Confidence Rankings of all gates of Bulgarian [n^{j}a], Audio Condition.

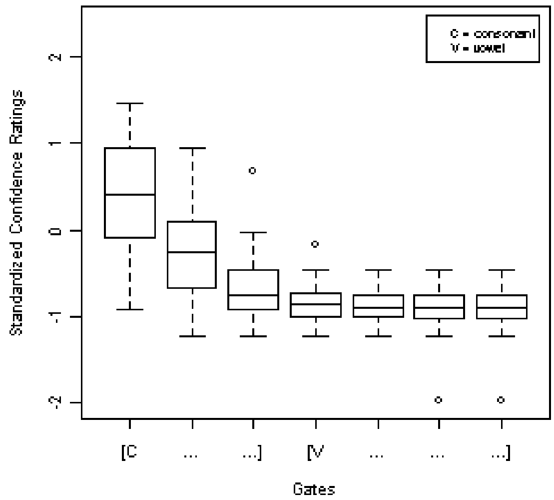


Boxplots of Confidence Rankings of all gates of Russian [n^{j}am], Audio Condition

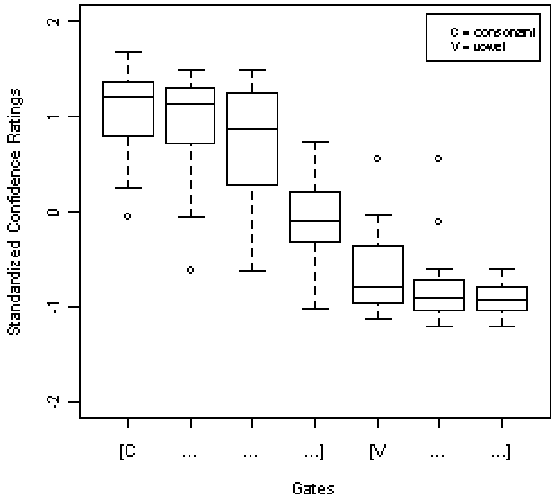
Appendix 5. Boxplots of the Words Containing the Approximants /l r n lʲ rʲ nʲ/ in the Context of the Vowel /u/, Audi-Only Condition



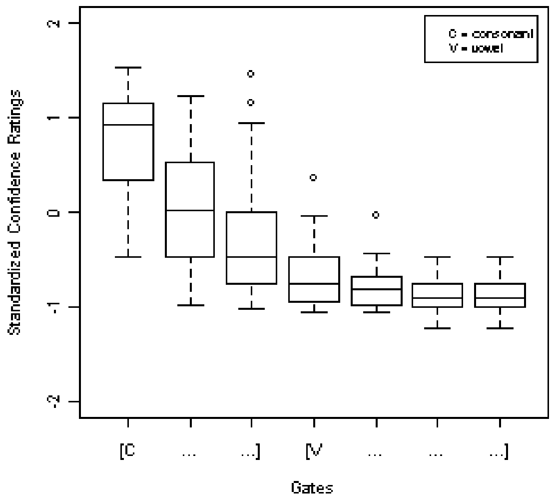
Boxplots of Confidence Rankings of all gates of Bulgarian [lu], Audio Condition.



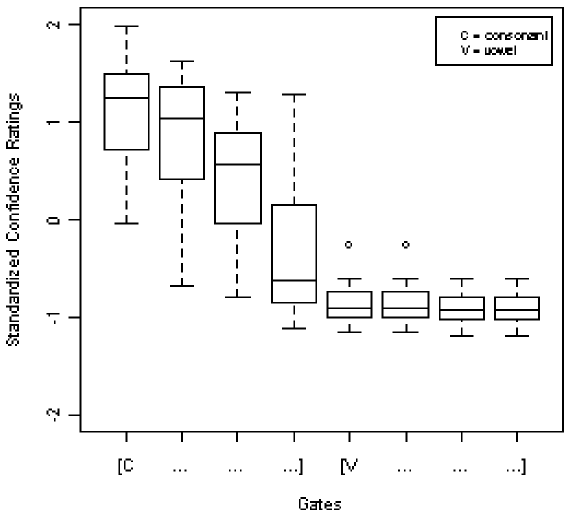
Boxplots of Confidence Rankings of all gates of Russian [luk], Audio Condition



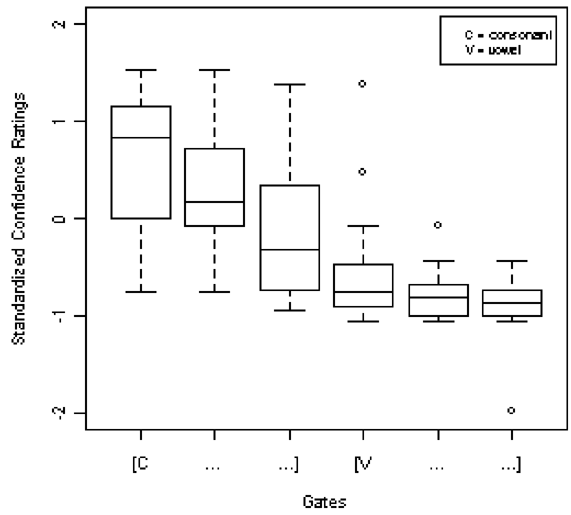
Boxplots of Confidence Rankings of all gates of Bulgarian [rup], Audio Condition.



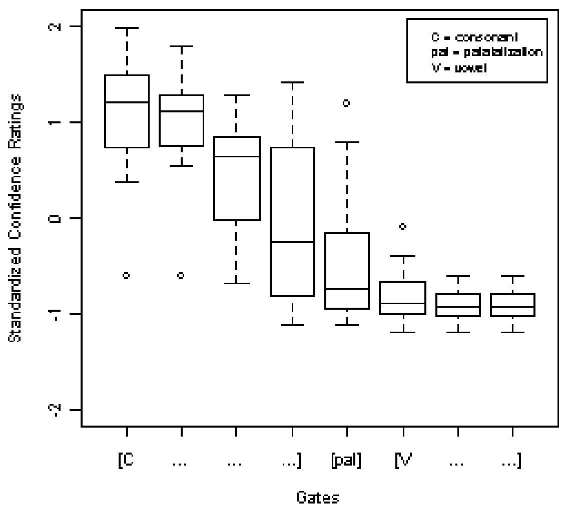
Boxplots of Confidence Rankings of all gates of Russian [rumba], Audio Condition



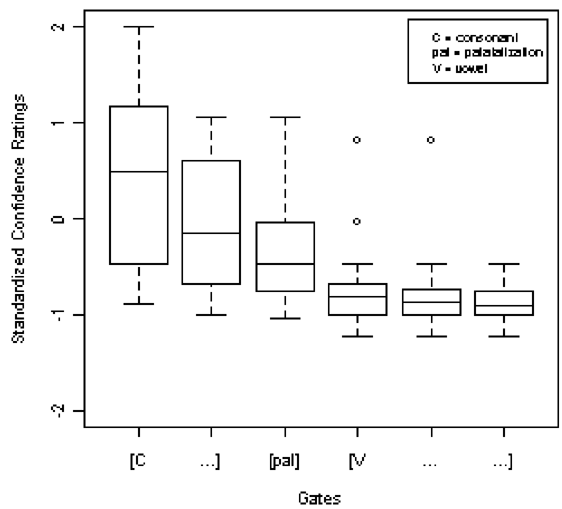
Boxplots of Confidence Rankings of all gates of Bulgarian [nuga], Audio Condition.



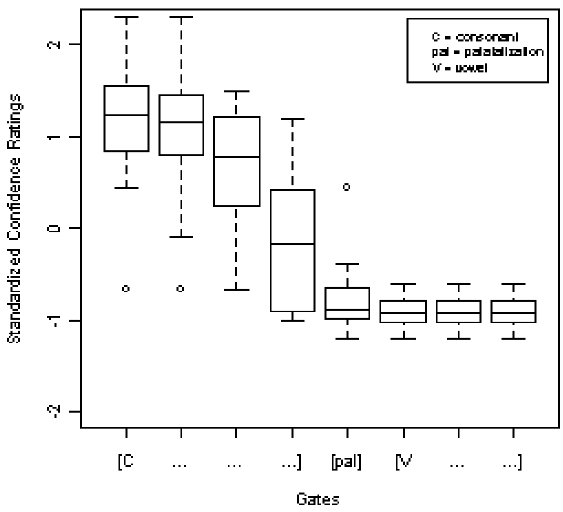
Boxplots of Confidence Rankings of all gates of Russian [nuga], Audio Condition



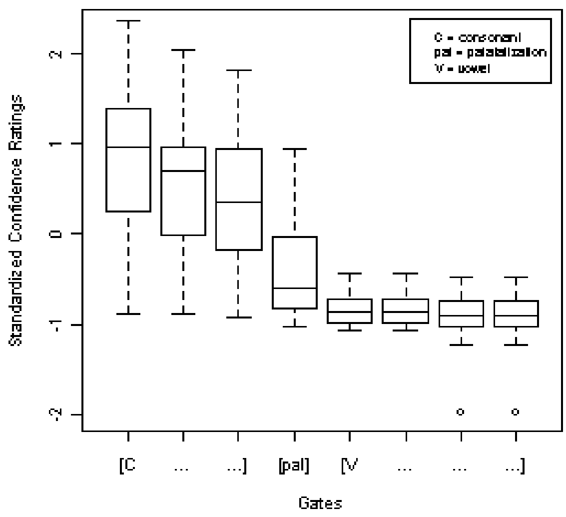
Boxplots of Confidence Rankings of al gates of Bulgarian [l^{j}uk], Audio Condition.



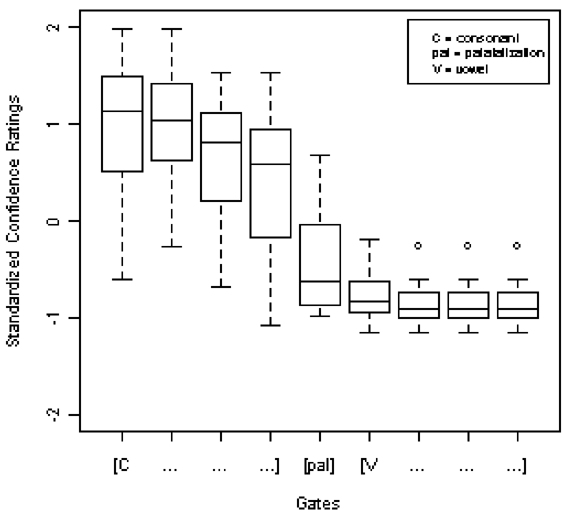
Boxplots of Confidence Rankings of all gates of Russian [l^{j}uk], Audio Condition



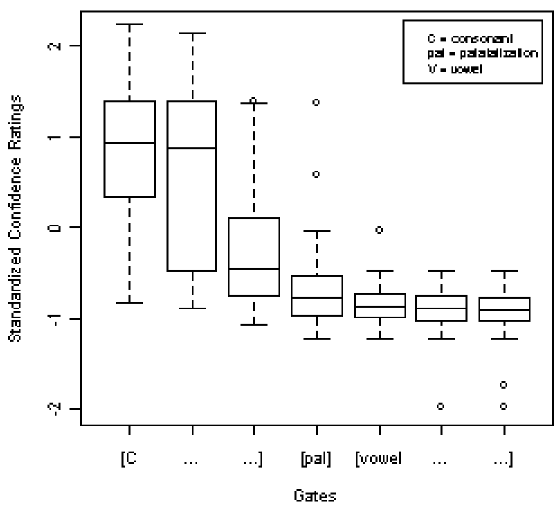
Boxplots of Confidence Rankings of all gates of Bulgarian [rʲup], Audio Condition.



Boxplots of Confidence Rankings of all gates of Russian [rʲumka], Audio Condition



Boxplots of Confidence Rankings of all gates of Bulgarian [nʲux], Audio Condition.



Boxplots of Confidence Rankings of all gates of Russian [nʲux], Audio Condition