Articulatory analysis of palatalised rhotics in Russian
Implications for sound change

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"La erre está palatalizada.
¿Quién la despalatalizará?
El quien la despalatalice,
¡buen despalatalizador será!"
Félix Rivas Trillo

Contents

Zusammenfassung

In dieser Arbeit wird der Frage nachgegangen, ob bestimmte Lautwandelprozesse phonetische Ursachen haben können und ob diese Ursachen in der synchronen Variation von Lauten erkenntlich sind. Das Hauptaugenmerk dient dabei palatalisierten Vibranten in Slawischen Sprachen. Es wurde oft beobachtet, dass der palatalisierte Vibrant /r^{j}/ aus diachroner Sicht ein instabiler Laut ist und sich oft wandelt (Broch 1910, Hock 1991: 133-135, Carlton 1991, Kavitskaya 1997). So haben mehrere slawische Sprachen diesen Laut im Laufe der Zeit verloren, sei es durch den Zusammenfall mit dem nicht-palatalisierten Vibrant (z.B. Weißrussisch; auch Schottisch Gälisch, Estnisch, wortfinal im Ukrainischen, Carlton 1991, Stadnik 2002), durch die Umwandlung in die Sequenz von zwei Lauten /r^{j}/ zu /rj/ (Slowenisch, Carlton 1991: 311; einige Dialekte des Ukrainischen, Jakobson 2002: 216) oder durch die Spirantisierung (/r^{j}/ zu /r̝/, /ʒ/, im Tschechischen und Polnischen Carlton 1991: 236, 251, Stieber 1973: 49).

Wenn ein Lautwandelprozess unabhängig voneinander in mehreren auch unverwandten Sprachen stattfindet, lässt sich vermuten, dass er einen phonetischen Grund haben könnte (Ohala 1993). Es wurde oft vorgeschlagen, dass die diachrone Instabilität von /r^{j}/ vor allem daran liegen könnte, dass die Zungenspitzen-Vibration und die sekundäre Palatalisierung artikulatorisch inkompatibel sind (Ladefoged and Maddieson 1996: 221, Kavitskaya 1997, Kavitskaya et al. 2009). Denn damit die Zungenspitze vibrieren kann, muss sich der Zungenrücken weiter hinten in der Mundhöhle platzieren und stabilisieren (Recasens 2013a, Proctor 2009). Die sekundäre Palatalisierung impliziert dagegen, dass sich der Zungenrücken hochhebt. In dieser Arbeit wird es also untersucht, ob die phonetische Natur der palatalisierten Vibranten einen Aufschluss über deren diachrone Instabilität geben kann.

Die vorliegende Dissertationsarbeit besteht aus fünf Kapiteln: Einleitung, drei Hauptkapitel und Schluss. Die Einleitung liefert die allgemeine Information zum Thema. Zunächst wird beschrieben, was man in Phonetik unter sekundärer Palatalisierung versteht.

Der Begriff sekundäre Palatalisierung bezeichnet einen Prozess, wenn die Artikulation eines Konsonanten mit der gleichzeitigen Zungenhebung Richtung harter Gaumen realisiert wird (Pompino-Marschall 2003). Die sekundäre Palatalisierung betrifft fast alle Konsonanten im Russischen: sie können palatalisiert oder nicht-palatalisiert, unabhängig vom vokalischen Kontext oder Wortposition, auftreten (Bondarko 2005).

Diese Arbeit beschränkt sich auf die Analyse von palatalisierten und nicht-palatalisierten Vibranten und Laterale des Russischen. Diese Konsonanten werden oft zur natürlichen Klasse der Liquida gezählt (Maddieson 1980: 73). Obwohl es sich als schwierig erwiesen hat, eine gemeinsame artikulatorische Eigenschaft für diese beiden Arten von Konsonanten zu finden (Wiese 2001a), gibt es dennoch viele Hinweise darauf, dass sie zusammengehören.

Es wurde oft beobachtet, dass Vibranten und Laterale aus diachroner Sicht ein asymmetrisches Muster aufweisen. Schon das Proto-Slawische hatte eine phonologische Opposition zwischen palatalisierten und nicht-palatalisierten Vibranten und Lateralen (Carlton 1991: 159, Shevelov 1964: 207). Während die Opposition zwischen den Lateralen in vielen modernen Slawischen Sprachen erhalten geblieben ist, wurde die Opposition zwischen den Vibranten oft aufgelöst (Kochetov 2005). Der Grund für die diachrone Instabilität von der Opposition zwischen /r^{j}/ und /r/ wird oft in der Artikulation von palatalisierten Vibranten gesehen. Es wird angenommen, dass die Palatalisierung und die Zungenvibration in einem Konflikt stehen, weil sie gegensätzliche Bedingungen an den Zungenrücken stellen: er muss sich heben wegen der Palatalisierung, muss sich aber gleichzeitig auch zurückziehen und stabilisieren, damit die Zungenspitze vibrieren kann (Ladefoged and Maddieson 1996: 221). Es wird in dieser Arbeit also versucht, die Artikulation von palatalisierten Vibranten zu analysieren und sie mit nicht-palatalisierten Vibranten und mit Lateralen zu vergleichen. Als Untersuchungsgegenstand wurde das Russische gewählt, denn diese Sprache hat den Kontrast zwischen palatalisierten und nicht-palatalisierten Vibranten in allen Wortpositionen bewährt.

Die Daten werden im Licht der Artikulatorischen Phonologie (Browman and Goldstein 1992), des DAC-Models (Recasens et al. 1997) und Ohala's Lautwandel-Theorie (Ohala 1993) analysiert. Die Artikulatorische Phonologie und das DAC-Modell vertreten den Sprecher-orientierten Ansatz und versuchen den Lautwandel aus der Sicht der Artikulation zu beschreiben. Ohala sieht dagegen eine größere Bedeutung für den Lautwandel in der Wahrnehmung. Es wird hier also untersucht, ob sich die Lautwandelprozesse, die die palatalisierten Vibranten betroffen haben, mit den Sprecher- oder Hörer-basierten

Ansätzen erklären lassen.

In den Hauptkapiteln 2, 3 und 4 werden drei Lautwandelprozesse analysiert, die palatalisierte Vibranten beeinflusst haben: Kontrastneutralisierung zwischen /r^j/ und /r/, *Glide Insertion*, und Spirantisierung. Die Studie basiert auf einem artikulatorischen Experiment, dass mit sechs russischen MuttersprachlerIinnen mit Hilfe von elektromagnetischer Artikulographie (EMA) durchgeführt wurde. Die InformantInnen mussten Zielwörter vorlesen, die in einen Tragesatz eingebaut wurden. Die Zielkonsonanten /l/, /l^j/, /r/, /r^j/ sind in unterschiedlichen Wortpositionen (initial, medial, final), Vokalkontexten (/a/, /i/, /u/) und bei schnellem und normalem Sprechtempo aufgenommen worden. Die phonetische Umgebung und die Betonung wurden kontrolliert.

Im Kapitel 2 wird untersucht, warum die Opposition zwischen /r/ und /r^j/ öfter neutralisiert wird als zwischen /l/ und /l^j/ (z.B. Weißrussisch, Carlton 1991: 299). Die Literaturrecherche hat weiterhin gezeigt, dass die Positionen wortfinal und vor vorderen Vokalen (z. B. /i/) besonders "gefährlich" für die Opposition /r^j/-/r/ zu sein scheinen (z.B. Ukrainisch, Carlton 1991: 283; einige Dialekte des Russischen, Obnorskij et al. 1949). Dagegen ist der phonologische Kontrast in der Position vor nicht vorderen Vokalen (z. B. /a/) am stabilsten. Es gibt viele Beispiele in der Literatur, die zeigen, dass die Positionen wort-final und vor vorderen Vokalen besonders anflig fr die Lautwandelprozesse sind (Hock 1991: 95-96, (Recasens 2014: 106, 142)). Viele von diesen Lautwandelprozessen werden aus der artikulatorischen Perspektive erklärt. Zum einen, sollen wort-finale Laute mehr reduziert artikuliert sein, als wort-initiale Konsonanten (Krakow 1999). Zum anderen, soll der hohe vordere Vokal /i/ einen starken Einfluss auf die Artikulation von benachbarten Lauten ausüben (Recasens et al. 1997). Daher wurde in dieser Arbeit angenommen, dass die Kontexte wort-final und vor vorderen Vokalen auch für phonologische Opposition zwischen den Vibranten gefährlich sein können. Da der artikulatorische Unterschied zwischen diesen beiden Lauten schon ziemlich klein ist, wird er in diesen Positionen besonders beeinträchtigt.

Um den artikulatorischen Unterschied zwischen palatalisierten und nicht-palatalisierten Konsonanten jedes Paares zu untersuchen (also zwischen /r^j/ und /r/, /l^j/ und /l/), wurde die Mahalanobis-Distanz zwischen den Zungenrücken-Positionen ausgerechnet (s. detaillierte Beschreibung der Methode in De Maesschalck et al. 2000). Die Ergebnisse haben gezeigt, dass die Mahalanobis-Distanz zwischen /r^j/ und /r/ kleiner ist, als zwischen /l^j/ und /l/ (in übereinstimmung mit den Ergebnissen in Kochetov 2005). Die Distanz wurde aber von den Faktoren Wortposition, vokalischer Kontext oder Sprechtempo fast nicht beeinflusst. Die Analyse von vertikalen und horizontalen Positionen des Zungenrückens im palatalisierten /r^j/ und /l^j/ hat gezeigt, dass der Zungenrücken in /r^j/ in wortfinaler Position nicht reduziert wurde. Dieses Ergebnis ist entgegen der Annahme, dass die Konsonanten in wort-finaler Position reduziert sind. Es ist aber in übereinstimmung mit der Annahme, dass Vibranten sehr eingeschränkte Laute sind (Recasens 2013a). Durch die Annahmen von AP und DAC lässt sich aber nicht erklären, warum die Opposition zwischen /r^j/ und /r/ wort-final und vor vorderen Vokalen zur Neutralisierung tendiert. Der Perzeptionsansatz wurde dazu gezogen, um diesen Lautwandel zu erklären.

Im Kapitel 3 wird der Lautwandel analysiert, der durch glide insertion entstanden ist. In Slowenisch, Untersorbisch und einigen Dialekten des Ukrainischen hat der palatalisierte Vibrant sich zu der Sequenz /r + j/ gewandelt. Um diesen Lautwandel zu analysieren, wurde die zeitliche Koordinierung (Timing) zwischen der Zungenspitze und dem Zungenrücken in palatalisierten Vibranten und Lateralen /r^j/ und /l^j/ analysiert. Die Zielkonsonanten wurden in drei Wortpositionen und im Kontext von /a/-Vokal analysiert. Zum einen hat diese Analyse die Ergebnisse von Kochetov (2005) bestätigt und auf weitere Wortpositionen erweitert, indem gezeigt wurde, dass das Timing zwischen den beiden Gesten sequentiell in Vibranten aber simultan in Lateralen ist. Das heißt, die Palatalisierung tritt in Vibranten erst nach der Vibration ein. Außerdem wurde festgestellt, dass die Koordination zwischen zwei Gesten weniger stabil in Vibranten ist, im Vergleich zu den Lateralen. Diese Befunde haben die Hypothese bestätigt, dass die sequentielle zeitliche Koordinierung zwischen Vibration und Palatalisierung eventuell die Ursache für den Lautwandel /r^j/ zu /rj/ im Slowenischen sein könnte.

Im Kapitel 4 wird der Einfluss der sekundären Palatalisierung auf die Zungenspitze in Vibranten und Lateralen analysiert. Im Polnischen und Tschechischen ist der palatalisierte Vibrant zu einem Frikativ umgewandelt. Es könnte unter anderem daran liegen, dass die Zungenspitze nicht so gut vibrieren kann, wenn die sekundäre Palatalisierung mitartikuliert werden soll. Es ist bekannt, dass sehr viele Faktoren übereinstimmen müssen, damit die Vibranten richtig artikuliert werden können. Frühere Studien haben beobachtet, dass die Initiation der Vibranten mit einer sehr schnellen Zungenspitzenbewegung realisiert wird (Hoole et al. 2013, Howson and Kochetov 2015, Scobbie et al. 2013). Bisher wurde aber nie systematisch analysiert, ob die Zungenspitzen-Geschwindigkeit für die Produktion von Vibranten wichtig ist. Wenn dem so ist, wäre es auch interessant zu untersuchen, wie die sekundäre Palatalisierung die Zungenspitzengeschwindigkeit beeinflusst.

In dieser Studie wurde die Bewegung der Zungenspitze aus ihrer Ruheposition hin zur Zielposition in Vibranten und Lateralen genauer untersucht. Drei Elemente wurden

gemessen: maximale Geschwindigkeit der Zungenspitze, der Abstand zwischen der Ruhe- und Zielposition und Stiffness. Stiffness ist die Normalisierung der Geschwindigkeit durch den Abstand (Roon et al. 2007), denn reine maximale Geschwindigkeit kann von vielen Faktoren beeinflusst werden. Die Ergebnisse zeigen, dass die Zungenspitze in Vibranten viel schneller ist als in Lateralen. Es wurde weiterhin herausgefunden, dass die Zungenspitze im palatalisierten Vibrant langsamer ist als in einem nicht-palatalisierten Vibrant, obwohl beide die gleiche Strecke zurücklegen müssen. In Lateralen ist die Situation genau umgekehrt. Dieses Ergebnis könnte eine Bestätigung dafür sein, dass die Palatalisierung die Zungenspitzenbewegung in Vibranten beeinträchtigt.

Im letzten Kapitel 5 werden die wichtigsten Befunde und Ergebnisse zusammengefasst. Aus den eben beschriebenen Versuchen kann man schließen, dass die Artikulation von palatalisierten Vibranten für ihre diachrone Instabilität verantwortlich ist. Erstens unterscheiden sich palatalisierte Vibranten wenig von den nicht-palatalisierten Vibranten im Vergleich zu palatalisierten und nicht-palatalisierten Lateralen (gemessen in der Zungenrückenpositionen). Zweitens, ist die zeitliche Koordination zwischen der primären und sekundären Gesten sequentiell und wenig stabil in /r^j/, aber nicht in /l^j/. Außerdem ist die Zungenspitze langsamer in /r^j/ im Vergleich zu /r/, obwohl die Zunge die gleiche Strecke zurücklegt. All diese Befunde deuten darauf hin, dass /r^j/ artikulatorisch schwer zu produzieren ist. Dies könnte der Grund dafür sein, dass dieser Laut diachron instabil ist und oft einen Lautwandel durchmacht, im Vergleich zu /l^j/. Einschränkungen der Studie und Ausblick werden präsentiert.

Abstract

The present work investigates the articulatory variation of palatalised and plain rhotics and laterals in Russian. It has often been often observed that palatalised rhotics are diachronically quite unstable, which has been attributed to the articulatory incompatibility between trilling and palatalisation. The sound changes which affected palatalised rhotics in Slavic languages can be divided into three categories (Kavitskaya 1997, Carlton 1991)[1]:

- **contrast neutralisation**: palatalised /r^{j}/ and plain /r/ merge into /r/ (Chapter 2)
- **glide insertion**: /r^{j}/ changes into a sequence of plain /r/ followed by a glide /j/ (Chapter 3)
- **spirantisation**: /r^{j}/ changes into a fricative trill /r̝/ or a postalveolar fricative /ʒ/ (Chapter 4)

Although laterals and rhotics belong to the same class of liquids (Proctor 2009, Kochetov 2005), the phonological opposition between /l^{j}/ and /l/ has been neutralised less often than between /r^{j}/ and /r/. I, therefore, aim to investigate whether the comparison between rhotics and laterals could shed light on the diachronic instability of the phonological opposition between /r^{j}/ and /r/ and of palatalised rhotics itself.

The main hypothesis to be tested in the present work is: since trilling and palatalisation are incompatible articulatorily, then the articulation of palatalised rhotics should be greatly influenced by conditions such as word position, vocalic context, or speech rate. There should therefore be a notable reduction of the secondary gesture in /r^{j}/ resulting in a greater articulatory similarity with the plain /r/ under certain conditions. There should also be an increased overlap between the palatalisation gesture and the following vowel, which could lead to the interpretation of delayed F2 transitions as a separate glide and

[1]In the structuralist framework (Martinet 1952), all three changes imply the loss of phonemic contrast: palatalised and plain rhotics stop being part of the opposition [+/- pal].

the change from /r^{j}a/ into /rja/. Moreover, the tongue tip in palatalised rhotics but not in laterals would be negatively influenced by the secondary gesture, which could be one of the reasons for the spirantisation of /r^j/.

In the introductory chapter, I summarise the relevant information on secondary palatalisation. Then, I present the cross-linguistic evidence for the diachronic instability of palatalised rhotics and the incompatibility between trilling and palatalisation in general. Then, I elaborate on the articulatory and acoustic properties of palatalised and plain liquids in Russian. The introductory chapter concludes with the summary of articulation-based theories Articulatory Phonology (Browman and Goldstein 1992), and DAC-model (Recasens et al. 1997), and perception-based account (Ohala 1993) on sound change.

The second chapter presents the analysis of the articulatory difference between palatalised and plain rhotics and laterals and the variability in the secondary gesture articulation. The articulatory distance between the palatalised and the plain consonant of each pair in their tongue dorsum positions was analysed, due to the fact that the raised tongue dorsum is the primary cue for palatalisation. The results confirm previous findings (Kochetov 2005) that the articulatory distance is smaller between rhotics than between laterals. Contrary to my hypothesis, the articulatory distance between palatalised and plain rhotics was not influenced by word-position, vocalic context, or speech rate. The results from the subsequent analysis of the secondary gesture in palatalised liquids suggest that the secondary gesture is highly constrained in palatalised rhotics but more variable in palatalised laterals. This poses a problem for the articulation-based account (Articulatory Phonology, Browman and Goldstein 1992, Bybee 2015), which argues that gestural reduction and reduction in gestural magnitude are the driving force in sound change.

The third chapter deals with the temporal organisation between the primary and the secondary gestures in palatalised rhotics and laterals. Here, I show that the timing between the two gestures is more variable and sequential in /r^j/ than in /l^j/. Since the secondary gesture and the following low vowel greatly overlap at a faster speech rate, the prominent F2-transitions associated with delayed palatalisation might be re-interpreted by the listener as a glide.

In chapter four, I analyse the influence of the secondary gesture on the tongue tip gesture in palatalised rhotics and laterals. The assumption to be tested here is that, provided the fast tongue-tip raising gesture is important for the articulation of alveolar rhotics, the secondary gesture will influence the tongue-tip velocity negatively.

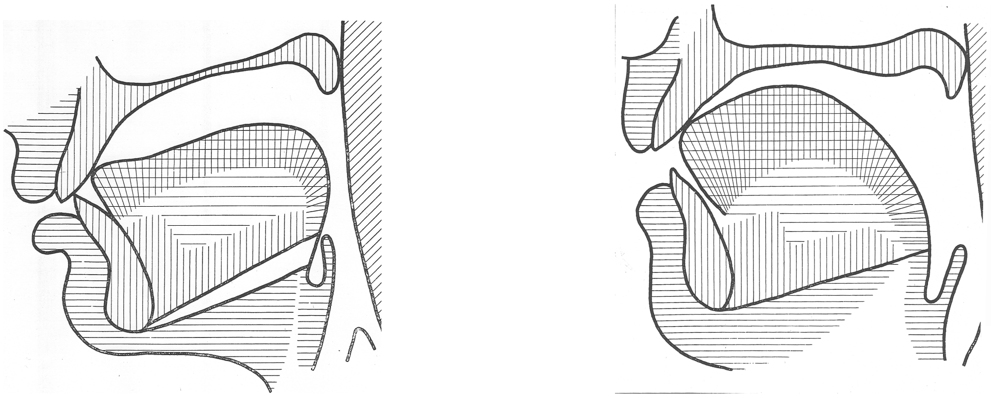
The conclusion chapter critically evaluates the results from the present analysis in the frameworks of Articulatory Phonology (Browman and Goldstein 1992) the DAC-model (Recasens et al. 1997), and the Ohala's (1993) perception model and suggests some ideas for further investigation. The present study has shown that the diachronic instability of a sound can have roots in its specific phonetic realisation.

Chapter 1

Introduction

1.1 Aim of the study

The aim of the present study is to investigate whether a detailed articulatory analysis of palatalised rhotics can provide us with a better understanding of the mechanisms of sound change which these sounds usually undergo. It has often been suggested that palatalised rhotics are diachronically unstable sounds mainly because of their articulatory complexity. In particular, the realisation of palatalised rhotics implies two antagonistic tongue dorsum gestures: the trilling requires the tongue dorsum lowering and stabilisation, which is in conflict with the tongue dorsum raising needed for palatalisation (Ladefoged and Maddieson 1996: 221). Thus, the main focus of the research reported in this thesis lies on the articulation of palatalised rhotics, which will be compared with their plain counterparts and with palatalised and plain laterals. By doing this, I particularly operate with the framework of Articulatory Phonology (Browman and Goldstein 1986, 1989, 1990a, 1990b, 1992, 1995, 2000), DAC-model (Recasens et al. 1997, Recasens 2007, Recasens and Espinosa 2009), as well as Ohala's perception model (Ohala 1981, 1993, 2012). In the framework of Articulatory Phonology, mainly two factors are responsible for many sound changes: reduction in gestural magnitude and increase in overlap between gestures (Browman and Goldstein 1991, Beckman et al. 1992, Bybee 2015). The DAC-model states that sounds differentiate in their degree of constraint and aggressiveness against neighbouring sounds. In contrast, Ohala attributes the primary role in the sound change to the listener. In the present study, these accounts will be applied to the empirical data in order to analyse whether they are able to explain the sound change processes that palatalised rhotics underwent.



(a) ɫ (b) l^j

Figure 1.1: Tracing from X-rays of a) a velarised lateral and b) a palatalised lateral in Russian (from Bolla 1981).

1.2 Palatalisation

1.2.1 Phonetic and phonological views on palatalisation

Palatalisation is one of the types of secondary articulation consisting of tongue dorsum raising towards the hard palate, which occurs more or less simultaneously with the primary consonant articulation (e.g. Ladefoged and Maddieson 1996: 355, 363-365, Ladefoged 2001: 316, Bondarko 2005, Hall 2000a: 16). Figures 1.1a and 1.1b show X-ray images of palatalised and plain laterals in Russian. It can be observed that the tongue dorsum is raised in [l^j], while it is flat or even concave during the articulation of [ɫ]. Obviously, the palatalisation is not just an added gesture. As Bondarko (2005) notes, only palatalised labial consonants present a case where the raising tongue dorsum does not interfere with the primary consonant articulation, i.e. labial occlusion. In alveolar, velar, or uvular consonants, the simultaneous tongue dorsum raising necessarily causes a change in the primary constriction location or duration (Ladefoged and Maddieson 1996: 364-365). Thus, the tongue tip is slightly retracted in a palatalised lateral as compared to its plain counterpart (Kochetov 2005). The term “secondary gesture” will be used in the present study to refer to the tongue dorsum raising in palatalised consonants.

The term “palatalisation” can also refer to the historical sound change when a consonant changes the primary place of articulation mostly due to the influence of a high front vowel or a glide (Ladefoged 2001: 245, Kochetov 2011, Bateman 2007). In English, for instance, alveolar consonants [t], [d], [s], [z] changed into palato-alveolars [ʧ], [ʤ], [ʃ], [ʒ] in contact with a palatal glide, as in examples *face* - *facial* (Kochetov 2011). However, the present study is concerned only with the phonetic definition of this term, i.e. the palatalisation as the secondary articulation of consonants.

It is important for the further discussion to differentiate between palatal and palatalised consonants. Compare, for instance, the palatalised and palatal lateral approximants /lʲ/ and /ʎ/ from Russian and Spanish. In the former, the tongue tip actively participates in the articulation of the sound; the tongue tip constriction occurs more or less simultaneously with the tongue dorsum raising (Figure 1.1b). However, there is no tongue tip contact during the articulation of the palatal /ʎ/ (Ladefoged and Maddieson 1996: 189); the occlusion occurs between the tongue body and palate (Ladefoged and Maddieson 1996: 189, Stadnik 2002: 27). Thus, palatalised consonants are usually described as sounds with complex articulation, while palatal consonants are supposed to be articulated with one whole gesture (Recasens 2014: 32-33; see also Recasens and Romero 1997 on palatalised and palatal nasals).

Consonants in almost all languages of the world can present some degree of palatalisation, mostly due to the coarticulation with neighbouring front vowels or glides (phonetically palatalised consonants). For instance, German and English consonants are slightly palatalised when followed by high vowels (Ordin 2010). But comparatively few languages have developed a phonological opposition between palatalised and non-palatalised consonants when the realisation of a palatalised or plain consonant does not depend on the phonetic context in which it is produced. Ladefoged and Maddieson (1996: 355) claim that palatalisation is not as frequent a type of secondary articulation, as for example labialisation is. Nevertheless, many languages have the opposition between palatalised and plain consonants (32 out of 112 languages investigated in Bateman 2007 have this opposition; see also overviews in Bhat 1978, Stadnik 2002, Kochetov 2011, among others). Slavic languages present a famous example of secondary palatalisation as a phonemic feature. Especially the Russian language makes an extensive use of the opposition between palatalised and plain consonants (Bondarko 2005).

1.2.2 Brief description of Russian phonetics and phonology

Secondary articulation like palatalisation has often attracted research interest; a considerable body of work has been dedicated to the analysis of this phenomenon, especially from the acoustic and perceptual points of view (Sinder et al. 1964, Diehm 1998, Zsiga 2000, Padgett 2003, Pritchard 2012, Bolanos 2013). Palatographic and X-ray analyses of palatalised consonants can be found in works of Koneczna and Zawadowski (1956), Skalozub (1963) or Bolla (1981). More, recently, studies performed by Kochetov (by means of Electromagnetic Articulography: 2002, 2005, 2006b, 2009), Kedrova and colleagues (by means of MRI: Kedrova et al. 2008, 2010) and others (Pompino-Marschall and Żygis 2003 on Polish; Gick et al. 2006 on Serbo-Croatian with ultrasound) provided a more comprehensive description of the articulation of palatalised consonants. Nevertheless, a more detailed analysis of the interplay between primary and secondary gestures in palatalised consonants is needed in order to understand how the palatalisation is realised.

Russian has five vocalic phonemes[1] /a, e, i, o, u/ and 35 consonant phonemes (Avanesov 1974, Vinogradov 1960: 49). As mentioned earlier, the secondary palatalisation is a distinctive phonological feature in Russian, meaning that almost all consonants participate in the opposition of palatalised vs. plain. However, since palatalisation implies a relationship between the consonant and the vowel, it is not always clear whether this feature has a phonological status in a given language. Sometimes it is also difficult to decide which of these two classes bears the phonological distinction and which presents an allophonic variation associated with it (see Stadnik 2002: 25). Even in Russian, where the opposition between palatalised and plain consonants is undoubtedly phonemic[2], there is still a debate on whether velar consonants are phonemically or just phonetically palatalised, due to only a few minimal pairs with palatalised and plain velar consonants. In the same line, there is also an unsolved issue about whether the contrast before a mid-high front vowel /e/ is phonemic, in Russian. Most consonants are realised as palatalised ones in the context before the vowel /e/ in this language. However, there are some foreign words, where a non-palatalised consonant is articulated before /e/ (Ordin 2010). As a result, a few minimal pairs have been created (ex. 1.1). The issue of functional load and the marginality of phonemic contrast is always a debate in phonological theories and is beyond the scope of the present study.

(1.1) /m^{j}er/ 'measure (PL.Gen)' vs. /mer/ 'burgomaster')

(1.2) /gor^{j}ko/ 'bitter' vs. /gorka/ 'slide'

[1] There is a long standing discussion on the phonemic status of ɨ-vowel. Some researchers consider it as a separate phoneme, while others see it as an allophone of /i/ (see Popov 2004: 72-93 for discussion). Since [i] always appears after palatalised consonants and [ɨ] after plain ones, they will be considered as allophones of the phoneme /i/ in the present study.

[2] But see an opposite view in Bratkowsky (1980).

(1.3) /pol^{j}ka/ 'Pole(fem)' vs. /polka/ 'shelf'

(1.4) /vol^{j}na/ 'free' vs. /volna/ 'wave'

The contrast between palatalised and plain consonants is preserved in all positions in Russian: before vowels, in word-final position and also in pre-consonantal position. Rhotics and laterals can also be realised as palatalised or plain. In pre-consonantal position, both rhotics and laterals are distinctive before labials and velars, but laterals are distinctive also before alveolars (ex. 1.2-1.4, Kochetov 2005, Vinogradov 1971: 47-51). Both plain and palatalised rhotics and laterals are relatively common phonemes in Russian (Bondarko et al. 1977, Smirnova and Chistikov 2011). All four consonants can occur word-initially and word-finally. Palatalised laterals occur more often word-finally than plain laterals (ca. 1250 vs. 700 words, Zaliznjak 1987); mostly in words of foreign origin: /gosp^{j}ital^j/ 'hospital', /pedal^j/ 'pedal', etc. In contrast, word-final palatalised rhotics are less common than the plain ones (ca. 210 vs. 2130 words). Many word-final palatalised rhotics mark the imperative verb forms (ex. 1.5).

(1.5) Minimal pair: /udar/ 'strike' vs. /udar^j / 'strike (Imp.)'

Palatalised consonants exert a notable influence on flanking vowels. The relative stability of the tongue dorsum or the complexity of palatalised consonants occurs at the cost of the vowels (see Öhman 1966, Purcell 1979). A consequence of this is the quite simple phonological system of five vowels with many allophones (Vinogradov 1960, Kuznetsova 1965, Ordin 2010). The vowels following or preceding palatalised consonants are much more fronted than in contexts with plain consonants (Matusevich 1976: 182-183, Vinogradov 1960: 56-57). The influence of preceding palatalised consonants seems to be stronger than that of subsequent consonants. For instance, the phoneme /a/ is articulated as [ɑ] when realised between two plain consonants; it is more fronted and has a diphthongoid character when preceded by a palatalised consonant and followed by a plain one; and is realised as [æ] when flanked by two palatalised consonants (Panov 1979: 149-153, Akišina 2009: 86-97).

1.2.3 Acoustic correlate of palatalisation

The primary acoustic correlates of palatalisation are the high second formant values in the palatalised consonant and in the flanking vowels (e.g. Öhman 1966, Purcell 1979, Halle 1959, Derkach et al. 1970, Shupljakov et al. 1970, Kavitskaya 2006). Perceptual analyses have shown that the transitions from or into flanking vowels play a decisive role in the perception of the presence or absence of palatalisation (Kavitskaya 2006, Kochetov 2002). For example, Bondarko (1998) describes an experiment where palatalised and plain consonants of Russian were recorded in VCV-sequences. The recordings were manipulated, so that the plain consonants were flanked by vowels from palatalised contexts and vice versa. The participants almost always identified palatalised consonants in a context of "plain" vowels as plain consonants, while plain consonants were identified as palatalised when flanked by "palatalised" vowels.

Secondary cues of palatalisation may also lie in longer acoustic durations or higher noise ratio (in plosives and fricatives) of palatalised consonants as compared to their plain counterparts (Kochetov 2002, Zsiga 2000, Bondarko 1998). Palatalised alveolar stops are usually produced with an audible burst at the consonant release due to the narrower constriction between tongue body and palate, which provokes some sort of audible turbulence (Matusevich 1976: 183, Kochetov 2002). Palatalised rhotics are more often realised as taps or approximants than plain ones (Iskarous and Kavitskaya 2010).

1.3 Palatalised and plain liquids in Slavic languages

1.3.1 Liquids as a phonological class

Rhotics and laterals are often grouped into a major natural class of *liquids* (Maddieson 1980: 73), although the attempts to find a common acoustic or articulatory property have been shown to be a difficult task (Wiese 2001a). However, the studies in Proctor (2009) and Recasens (2013a) suggest that liquids may indeed have a common articulatory feature: a constrained tongue dorsum, which is actively involved in the production of both types of consonants.

Laterals and rhotics have much in common. For instance, they are the most sonorous oral consonants (Ladefoged and Maddieson 1996: 182) and can form a syllabic nucleus in several languages (Wiese 2001b, Beňuš 2014). Laterals and rhotics are allophones of one phoneme in some languages (e.g. Tukang Besi, Proctor 2009: 33 or Korean, Iverson and Sohn 1994). Both types of consonants often present similar phonotactic behaviour. In some languages, consonant clusters can be formed only with liquids as second consonants[3], where liquids usually occur near the vocalic nucleus. Rhotics and laterals are often subject

[3]Of the type Cr- or Cl-, where C is fricative or plosive consonant (Proctor 2009: 23-24).

to same sound changes: metathesis (Blevins and Garrett 1998), neutralisation (dialects of Spanish, Quilis 1999), alternation (rhoticisation of laterals and lateralisation of rhotics, Proctor 2009, Müller 2011), vocalisation, etc.

In Slavic languages, rhotics and laterals are also usually considered as belonging to the phonological class of liquids (Matusevich 1976, Bulanin 1970, Vinogradov 1960: 51, Carlton 1991). In Slovak and Czech, liquids can form a syllabic nucleus (Beňuš 2014, Carlton 1991). Both types of consonants participated in a variety of phonological changes (e.g. *tort/tolt*-variation, see Carlton 1991: 151-153). Although both /l/ and /r/ have their palatalised counterparts in most Slavic languages, the current distribution varies from language to language. Below, a more detailed description on the asymmetrical distribution of palatalised and plain liquids in modern Slavic languages will be presented.

1.3.2 Articulation of liquids

Articulation of lateral approximants

The most common type of lateral approximant is the dental or alveolar lateral approximant. These sounds are produced with central tongue tip or blade constriction and lowered tongue sides, where the air can freely flow through (Maddieson 1984: 76-77, Ladefoged and Maddieson 1996: 183-184). As in the case of alveolar trills, the articulation of laterals requires a stabilised tongue dorsum (Recasens 2013a, Proctor 2009, see Müller 2011 for more cross-linguistic data). However, the tongue dorsum is probably less constrained in the latter, as compared to the former (Recasens 2013a). Laterals do not require a strict control over the tongue tip, unlike trills. Indeed, coda laterals may even lack the tongue tip constriction, especially in the case of velarised laterals (Ladefoged and Maddieson 1996, Recasens and Espinosa 2010, 2005).

Cross-linguistically, laterals are often differentiated as "dark" and "clear". The term "dark" refers to laterals with tongue postdorsum raised towards the velum, i.e. velarised laterals. "Clear" laterals usually denote consonants without prominent tongue postdorsum gesture as in the case of German laterals or English onset laterals.[4] Recasens (2012a) investigated lateral approximants in 23 languages and found that languages differ in the degree of variability of these sounds. While some languages have strongly velarised laterals in all positions (i.e. Russian, Majorcan Spanish) or only "clear" laterals with little variation,

[4] As can be deduced, especially the term "clear" is very subjective. In the present study, the term "dark" will be used as a synonym for "velarised". See Chapter 3 for more detailed analysis on intergestural coordination in laterals.

most languages present considerable allophonic variation.

It is widely agreed that Russian /l/ is strongly velarised, while it is still unclear whether other non-palatalised consonants of Russian are velarised or not (Kedrova et al. 2011). In Polish, “clear” laterals are velarised before low and back vowels, and are palatalised when followed by high vowels (Stolarski 2010). These data suggest that lateral approximants, unlike alveolar trills and taps, can be produced with variable articulation and are good hosts for palatalisation (Hall 2000b).

Laterals in Russian

Russian palatalised and plain laterals are produced with central tongue tip occlusion; one or both lateral sides of the tongue are lowered, so that the air can flow through freely (Bulanin 1970: 66-67, Matusevich 1976: 151-152). Plain laterals are apical, postdental or alveolar, and strongly velarised. The predorsum is lowered and takes a concave form, the postdorsum is raised toward the velum. Palatalised laterals are described as apical by Matusevich (1976: 152-152) but as dorsal by Bulanin (1970: 66-67) and Hall (2000b), and are produced with some lip protrusion. Laterals, as well as rhotics, are partly devoiced in word-final position before a pause (Matusevich 1976: 189).

Articulation of alveolar rhotics

Alveolar trills require a precise articulatory control over the whole tongue in order for the vibration to be initiated and maintained (Ladefoged and Maddieson 1996: 217-219, Solé 2002, McGowan 1992). The tongue predorsum has to lower, the postdorsum has to retract and to stabilise (Recasens and Pallarès 1999: 144, Solé 2002, Matusevich 1976: 155, Proctor 2009, Kavitskaya et al. 2009, Recasens 1991). The stabilised tongue dorsum allows the small portion of the tongue tip to move freely. As Kavitskaya et al. (2009) claim

> If the entire tongue is mobile and has the same effective mass, a great deal of the vibration energy would be dissipated in the by the [*sic*] more massive dorsum, inhibiting the vibration of the tip. Immobilization through retraction renders the dorsum highly massive and incapable of flutter.

The intraoral pressure also plays an important role in the production of trills. As Solé (1999: 407) argues, it “should be high enough to produce tongue tip vibration and low enough not to impair the transglottal flow required for voicing”. Howson et al. (2015) suggest, following McGowan (1992), that the lateral tongue bracing may be another important requirement in the production of trills.

Tongue tip vibration in trills occurs due to aerodynamic processes (McGowan 1992, Laver 1994: 218-219, Solé 1998, Solé 2002, Ladefoged and Maddieson 1996). The principle of vibration of the tongue tip is similar to the vocal fold vibration: first, the tongue tip rises towards the alveolar ridge, without necessarily touching it (taking the "critical position", Solé 2002). Meanwhile, the air from the lungs accumulates in the month cavity, and the intra-oral pressure starts to build up. Eventually, the intra-oral pressure overtakes the force of the tongue tip by pushing it away from the alveolar ridge. The air starts to escape from the mouth through the created opening. Due to the Bernoulli effect, the tongue tip is pulled back toward the alveolar ridge, and the intra-oral pressure starts to build up again (Laver 1994: 219). Trills usually have two to five cycles (Ladefoged and Maddieson 1996). The acoustic duration of each closed-open cycle is ca. 50 ms.

The articulatory difference between trills and taps is not very clear. Although taps are described as having one ballistic contact with the alveolar ridge (Catford 1982: 128-135, Solé 1999, Ladefoged and Maddieson 1996, Recasens and Espinosa 2007), alveolar trills imply more than one tongue tip contact and are realised due to the aerodynamic forces described above. Some languages differentiate between taps and trills phonemically (e.g. Spanish). Due to such complex articulation, trills often present much variation and can be realised as taps, fricatives, approximants or can be vocalised. Even in languages with phonemic contrast between trills and taps, the former might often present only one alveolar contact.

Rhotics in Russian

Palatalised and plain rhotics in Russian are apical: the tongue tip touches the alveolar ridge or the post-dental part (Matusevich 1976: 132-133, Bolla 1981: 99). Bulanin (1970: 67-68) states that palatalised and plain rhotics are produced with a tense, slightly curled back tongue tip and thus are cacuminal, with less curled tongue tip in /r^j/ than in /r/. Palatalised rhotics are slightly fronted in comparison to the plain ones (Bulanin 1970: 67, Kochetov 2005).

While they are usually described as trills, both plain and palatalised rhotics are most commonly realised as taps or approximants (Iskarous and Kavitskaya 2010). The production of rhotics depends on several factors like word position, speech tempo, emphatic speech, etc. Matusevich (1976: 155) states that plain rhotics have one or two cycles word-initially; they are typically produced with only one cycle intervocalically and usually present several, partly devoiced cycles word-finally. She claims that palatalised rhotics present the same number of cycles as /r/, but are much more often devoiced in word-final position than their plain counterparts (Matusevich 1976: 156). Similarly, Bolla (1981: 99) reports that both rhotics usually present three to four cycles, although produced with only one or two cycles in word-initial and intervocalic positions. For /r/, the tongue takes the position similar to the articulation of Russian /ʃ/ or /ʒ/, which have a slightly lowered predorsum (Bulanin 1970: 67). This description is in line with the findings in Howson et al. (2015) about Czech trills.

1.3.3 Incompatibility between trilling and palatalisation

Secondary palatalisation and trilling seem to be incompatible because they pose different articulatory requirements on the tongue (Kavitskaya 1997, Ladefoged and Maddieson 1996: 221, Widdison 1997, Żygis 2005, Solé 1999, 2002, Kavitskaya et al. 2009). The production of trilling requires the tongue body to retract and stabilise (Recasens 2013a, Proctor 2009). However, the tongue dorsum raising due to palatalisation interacts with this necessary condition. As a result, the tongue tip grows in mass (McGowan 1992, Kavitskaya 1997) and the whole tongue is advanced (Broch 1910, Kochetov 2005). In addition, the contact area between the tongue tip and the alveolar ridge increases (Broch 1910, Kavitskaya 1997, Skalozub 1963: 102). Consequently, the tongue tip is not able to trill freely as in the case of a plain /r/. Iskarous and Kavitskaya (2010) showed in an empirical study that palatalised rhotics are produced as taps or approximants in the most cases. Moreover, palatalised rhotics often display some period of offglide frication (Żygis 2005: 147).

Whereas Kavitskaya (1997) and Recasens (2014) see the reason for the incompatibility between trilling and palatalisation in antagonistic requirements posed on the tongue dorsum, Hall (2000b) sees the problem rather in the tongue tip itself. He claims that rhotics and retroflex consonants are bad hosts for palatalisation because they are necessarily produced with the tongue tip, unlike laterals or alveolar and dental consonants. According to Hall, the apical articulation would be negatively influenced by the raised tongue dorsum needed for palatalisation. A laminal articulation is inappropriate for trilling but seems to pose no problem for lateral sounds.[5] In addition, while rhotics are defined as sounds with one or more short contacts between the tongue tip and the palate, laterals do not neces-

[5] Remember that palatalised laterals have also been described as laminal by some researchers (e.g. Bulanin 1970: 66-67).

sarily have to present an occlusion (Ladefoged and Maddieson 1996: 182). The tongue tip position or grade of occlusion may vary considerably in a lateral approximant without having much influence on the acoustic output (Ladefoged and Maddieson 1996: 192). These findings suggest that the tongue tip gesture can vary in laterals but should be stable in rhotics.

Similarly, Yamane et al. (2015) claim that taps, although they do not have constricted tongue dorsum, are still quite resistant to palatalisation cross-linguistically, phonotactically, and diachronically. The authors suggest that this instability could be caused rather by the interference between the tongue tip and palatalisation than by the conflict between tongue dorsum retraction (required for trilling) and tongue raising (required for palatalisation).

Further evidence for incompatibility between trilling and palatalisation comes from languages like Spanish (Recasens 2014: 133), Bantu languages (Kavitskaya 1997; see many more examples in Hall and Hamann 2010), where rhotics seem to avoid the presence of high vowels.

It is commonly agreed that Proto-Slavic had palatalised and plain rhotics and laterals. However, palatalised rhotics have not been preserved in all modern Slavic languages. Some languages lost the secondary gesture in rhotics completely (e.g. in Belarusian, /rʲ/ changed to /r/). In Czech and Polish, /rʲ/ changed to a fricative (/r̝/ and /ʒ/, /ʃ/). Although laterals and rhotics present similar articulatory, acoustic and phonotactic properties, palatalised laterals do not seem to have any conflict between primary and secondary gestures. Unlike rhotics, the contrast between palatalised and plain laterals seems to be stable diachronically (if a language undergoes depalatalisation, laterals are the last sounds to be lost, e.g. Serbo-Croatian). The following chapter presents a detailed description of the formation of palatalisation contrast in Proto-Slavic and the outcomes of the palatalised rhotics in modern Slavic languages.

1.3.4 Diachronic evidence for asymmetry in contrast neutralisation between rhotics and laterals

Formation of palatalisation in Proto-Slavic

The present study is concerned with the loss of palatalisation contrast in rhotics in Slavic languages. However, it is essential to explain, first, how and at which temporal stage the opposition between palatalised and plain consonants evolved in Proto-Slavic. The following description in Hock (1991: 73) about the general principle of the formation of phonological palatalisation contrast is applicable to Proto-Slavic as well: "Palatalization consists in the partial assimilation of a consonant to a neighbouring front vocalic segment. [...] Like umlaut, palatalization and labiovelarization become phonologically significant through some other process which makes them unpredictable. More usually, this process consists in the loss of some of the conditioning environments".

Many researchers claim that first Proto-Slavic palatalised consonants were created through the process of *jotation*, when "a consonant and the following *j* merge to form a new segment" (Carlton 1991: 112, Iskarous and Kavitskaya ming). Through this process, the first palatalised consonants /l^j/, /n^j/, /r^j/ were created in Proto-Slavic in the fifth to eighth centuries and were in phonological opposition to their non-palatalised counterparts /l/, /n/, /r/ (Shevelov 1964: 217, Carlton 1991: 112-113, Eckert et al. 1983: 48-49). As a result, the contrast between palatalised and plain liquids was passed on to all Slavic languages (Carlton 1991: 159, Shevelov 1964: 207).

The second process which led to the formation of phonemic contrast between palatalised and plain consonants, as we know it from e.g. modern Russian, occurred later (12 to 15th century) and most probably did not affect to the full extent the South-Western group (i.e. Slovene, Serbo-Croatian, Macedonian, and West-Bulgarian, Carlton 1991: 160). It is assumed that consonants were first phonetically palatalised before front vowels in East- and West-Slavic groups. Through subsequent sound change processes like the fall of *jers* (high, lax, ultrashort vowels ĭ and ŭ, Carlton 1991: 165), cluster simplifications, and several morphological changes, palatalised consonants could also occur in the position before non-front vowels, before consonants, and word-finally. The newly created palatalised consonants fell together with the palatalised liquids and nasal from the jotation process. Consequently, the contexts of phonological contrast between palatalised and plain consonants increased in languages which participated in this second process (Eckert et al. 1983: 125-129, Carlton 1991).[6]

As mentioned above, not all modern Slavic languages created the full spectrum of palatalised and plain consonants. The South-Western group probably never developed the full phonological contrast (Carlton 1991: 160, Shevelov 1964: 489). Languages from the East-Slavic family (Russian, Ukrainian, Belarusian) were the most progressive in this sense by developing the correlation between palatalised vs. non-palatalised for the most

[6] However, Zhivov (1996) claims that palatal (see above) liquids and nasals and the newly created palatalised ones did not fall together in the East-Slavic group. In his opinion, a three-way opposition was created: palatal vs. palatalised vs. plain liquids and nasals. Later, palatal liquids and nasals were just lost without merging with the new palatalised ones.

consonants at a given historical period of time. The West-Slavic family (Polish, Czech, Upper- and Lower-Sorbian) occupies an intermediate position in this respect (Carlton 1991: 160). However, it is commonly assumed that all Slavic languages had the opposition between palatalised and plain liquids and alveolar nasals at some stage of their history, although the functional load varied considerably from language to language.

Phonetic nature of Proto-Slavic **rj*, **lj*, and **nj* reflexes

The question as to whether the outcomes of the process of jotation were palatalised or palatal liquids and nasal is still being debated (Stadnik 2002, Galinskaja 2004: 56). In Russian literature, the terms "soft", "half-soft" or "originally soft" are used to refer to palatalised or palatal consonants (Stadnik 2002: 34). The liquids and nasal outcomes from the jotation process are sometimes referred to as "originally soft"; a term which only refers to the diachronic aspect, but not to the phonetic nature of these sounds. Some authors understand under the term "originally soft" palatal consonants, as opposed to palatalised ones from posterior sound changes (Isačenko 1980). Another common opinion is that all outcomes of the sound changes described above were palatalised consonants (Shevelov 1964, Carlton 1991). Some studies even use both definitions "palatalised" and "palatal" as synonyms (Horlek 1992, Macaulay 1994: 101, as cited in Stadnik 2002: 34). However, as discussed earlier, the phonetic term "palatal" means the "change in primary place of articulation", while the term "palatalised" refers to secondary articulation consisting in raising the tongue dorsum, without changing drastically the primary place of articulation (Stadnik 2002: 26-27).

To discover how exactly these sounds were articulated is a necessary, although quite a challenging task. While palatal laterals and nasals are not uncommon in the languages of the world and even some modern Slavic languages have palatal laterals and nasals in their phonemic inventories (e.g. Croatian, Polish), the existence of palatal trills is highly questionable. A palatal trill would be produced with the vibration of the tongue dorsum against the palate, which is virtually impossible from the articulatory point of view, since the tongue body would not be able to participate in the mechanical vibration. Indeed, no palatal trills have been attested in cross-linguistic surveys (Maddieson 1984, Bhat 1978, Bateman 2007). As Hall (2000b: 15) claims "rhotics are universally immune to nonanteriorization (full palatalization), because the output of such a process would be a postalveolar laminal rhotic, a non-existent segment".

Stadnik (2002: 142-145) discusses this issue in much detail. She is aware of the articulatory impossibility of palatal trills and suggests that, instead, the outcome of the jotation process could have been either a trill-fricative as in Czech, a palatalised trill /r^j/ or even a sequence of a trill and a jod /rj/, while laterals and nasals became truly palatal. If those trills were trill-fricatives as in Czech, they would be produced with considerable frication (See Chapter 4 for more detail about the articulation of trill-fricatives). However, it is unlikely that trill-fricatives would have still been interpreted as palatalised consonants in order to be able to merge with newly created palatalised trills at a posterior stage. The assumption that the realisation of Proto-Slavic trills was the sequence of /r/ and /j/ is also controversial. In my opinion, the outcomes of the jotation process were palatalised - and not palatal - rhotics and laterals, which were passed on to all Slavic languages.

Reflexes of palatalised liquids in modern Slavic languages

Modern Slavic languages are traditionally divided into three groups (Schenker 1993: 60):

- South-Slavic: Bulgarian, Macedonian, Serbo-Croatian, Slovene
- West-Slavic: Czech, Slovak, Upper Sorbian, Lower Sorbian, Polish, Cassubian
- East-Slavic: Russian, Ukrainian, Belarusian

They present quite a manifold picture, as far as the secondary palatalisation is concerned. The number of still preserved contrasts between palatalised and plain consonants goes from almost absent or very few in the South-Slavic group, to very developed systems in East-Slavic languages. The West-Slavic group presents an intermediate stage (Carlton 1991). As mentioned earlier, it is assumed that the Proto-Slavic must have presented the contrast at least between palatalised and plain laterals, rhotics, and nasals. Some Slavic languages never went further to expand this phonological opposition to other consonants.

Many Slavic languages experienced the process of depalatalisation at some earlier stages of their history, neutralising the opposition between palatalised and plain consonants at least in some phonetic conditions. In general, labials and rhotics seem to be poor hosts for palatalisation (Hock 1991: 133-135, Kochetov 2002, Kochetov 2005, Stadnik 2002). The contrast is especially vulnerable in preconsonant coda position, word-finally, and before high vowels. The focus of the present analysis lies on palatalised trills, which will be compared to palatalised laterals. Although laterals and rhotics are grouped in the same class of liquids because of similar articulatory, acoustic and phonotactic properties, the opposition between palatalised and plain rhotics is more prone to be neutralised, unlike between palatalised and plain laterals (Broch 1910, Kochetov 2005), as will be seen from the following cross-linguistic analysis.

Complete merger between /r^j/ and /r/

The tendency for rhotics to depalatalise can be observed from the very beginnings of the history of Slavic languages (Broch 1910, Filin 1972). Written sources of Old Church Slavonic[7] present already the cases of depalatalisation of rhotics (Bondaletov 2005, Kul'bakin 1915: 46).

It is assumed that Serbo-Croatian, Slovene, Macedonian and West-Bulgarian have never developed the full palette of contrast between palatalised and plain consonants (Carlton 1991: 160). Nevertheless, these languages should have inherited the palatalised reflexes from the jotation process, which took place in Proto-Slavic. Modern Slovak presents the phonological contrast between palatalised and plain /l^j/, /d^j/, /t^j/, /n^j/ and /l/, /d/, /t/, /n/, but rhotics no longer participate in this contrast (Carlton 1991: 242, Greenberg 2000). Similarly, Serbo-Croatian has the contrast between palatalised and plain laterals and nasals, but not between rhotics (Carlton 1991: 330, Broch 1910). Macedonian neutralised the palatalisation contrast in all consonants, expect laterals and alveolar nasals (Carlton 1991: 324-325, Koneski 1983: 44-48). All these languages have only a plain rhotic in their phonemic inventories.

In Belarusian, most of the consonants still participate in the opposition palatalised vs. plain. However, the contrast between /r^j/ and /r/ was lost completely in favour of the plain rhotic (Carlton 1991: 299, Hlebka 1957: 82-83, Wexler 1977: 152-154, Krivitskij et al. 1990: 46-48).[8] The first written sources for this language exhibit the total merger of the two phonemes, it is thus not clear whether this process was gradual or abrupt. The contrast between palatalised and plain laterals is still active in all word positions.

Many dialects of Russian, the standard variant of which preserves the contrast between /r^j/ and /r/ in all positions, present considerable variation in the articulation of /r^j/. For instance, Sergeeva (1984: 108) reports that Russian dialects of the Kursk region often have a plain rhotic instead of /r^j/ (see also Obnorskij et al. 1949, Galinskaja 2004: 115-116, Galinskaja 2001: 156-157).

Loss of contrast in coda position

Some Slavic languages still preserve the contrast between /r^j/ and /r/ in some contexts

[7] Old Church Slavonic is the first Slavic written language, which "was created especially for the purpose of serving the needs of the Slavonic Orthodox church" (Gasparov 2001).

[8] Some dialects of Belarusian still present the opposition, which has probably been restored due to the contact with Russian (Kavitskaya 1997).

but lost it in others. Ukrainian, Bulgarian, Slovene, and Upper Sorbian no longer contrast between /r/ and /r^j/ in word-final position (Carlton 1991: 260-261, 282-283, 305-306, Shevelov 1964: 495-496, Shevelov 1979: 188-192, Zhovtobrjuch 1973: 12, Mirčev 1978: 150-151, Trofimowitsch 1977: 178). In contrast, the opposition between palatalised and plain laterals is still preserved in all word-positions in Ukrainian (Shevelov 1979). In Upper Sorbian, similarly to Polish, the opposition /l^j/-/l/ switched to /l/-/w/ (Carlton 1991: 260). In Bulgarian, however, the contrast between palatalised and plain laterals was also lost in word-final position (Carlton 1991: 306).

Standard Russian differentiates between /r/ vs. /r^j/ and /l/ vs. /l^j/ everywhere: in prevocalic-, syllable-, and word-final positions[9]. However, non-final coda /r^j/ was depalatalised in some contexts at earlier stages of Russian. Several works from the 60s of XX century state that the pronunciation of palatalised rhotics in pre-consonant position in some words should be considered obsolete at that time (Vinogradov 1960: 77, Péter 1969: 91, Isačenko 1980: 179, Krysin 2008: 283, Panov 1968: 57-58). Word-final /r^j/, unlike /l^j/, has been lost in toponyms like **Vladimirj*, which changed into "Vladimir" (place name), but not in *Jaroslavlj* (place name, Galinskaja 2004: 115-116).

Contrast neutralisation before front vowels

It is worth noting that the literature review does not provide strong evidence for the asymmetry between rhotics and laterals, as far as the neutralisation before front vowels is concerned. All consonants might be neutralised in this position (e.g. some dialects of Russian Avanesov and Orlova 1965: 85). Padgett (2001: 193) claims that there is a cross-linguistic tendency to avoid the contrast between palatalised vs. plain consonants before front vowels. Kavitskaya (1997, personal communication, February 24, 2016) also states that the contrast neutralisation between rhotics before front vowels may be due to perception rather than articulation. However, it has been shown that the articulatory difference between rhotics is smaller than between laterals (Kochetov 2005). In addition, rhotics, but not laterals, tend to avoid the contact with high vowels for articulatory reasons (Recasens 2014: 133). It can thus be hypothesised that the articulatory contrast between /r^j/ and /r/ is even more impaired under unfavourable conditions, like the presence of front vowels, compared to that between /l^j/ and /l/.

In Bulgarian, all consonants lost the contrast before front vowels *i*, *e* (Carlton 1991: 306). Many Ukrainian dialects often depalatalised the /r^j/ at the beginning of the XX century. At that time, some dialects preserved the opposition between palatalised and

[9] Palatalised and plain rhotics are contrastive in coda position before labial and velar consonants. Coda palatalised and plain laterals contrast before all consonants, except other laterals (Vinogradov 1971: 47-50).

plain rhotics only in a position before /a/ and sometimes before /u/. A plain rhotic was realised in all other positions, even before the front vowel /i/ (Zilyns'kyĭ 1932: 103-106). At earlier historical stages, some Ukrainian dialects probably also experienced a neutralization between palatalised and plain rhotics before front vowels. Kuraszkiewicz 1934 (as cited by Sherekh 1953: 17) gives some examples of the confusion between vowels [i] and [ɨ] after rhotics, which he attributes to the depalatalisation of /r^j/.

Trofimowitsch (1977: 179) states that the Upper-Sorbian phonemes /b^j/, /p^j/, /m^j/, /n^j/, textipar^j/, but not /l^j/, are less palatalised when followed by front vowels than by low vowels. Sergeeva (1984: 86) found the same asymmetry between /r^j/ and /l^j/ before front vowels for Russian dialects of the Vologda region (see further evidence for Russian dialects in Obnorskij et al. 1949, Filin 1972: 314-319).

Spirantisation

Czech, Polish, Upper- and Lower-Sorbian belong to the West-Slavic group and form the intermediate stage between the South-Slavic with few palatalised consonants and the East-Slavic group with an almost fully developed system. In Czech and Polish, the palatalised rhotic changed very early (ca. 13th century) to the trill-fricative /r̝/ (Stieber 1973: 49, Żygis 2005). Later, Polish /r̝/ changed further to a postalveolar voiced or voiceless fricative /ʒ/ or /ʃ/ (depending on the context), falling together with the already existing phonemes (Stieber 1973: 109-110). Since these fricative reflexes of Proto-Slavic /r^j/ lack a palatalised gesture, they no longer form part of the phonological opposition palatalised-non palatalised. Although the opposition between palatalised and plain laterals has also been neutralised in these languages (through complete merger in Czech or the change from /l/ to /w/ and from /l^j/ to /l/ in Polish), these processes are dated posterior to the spirantisation of /r^j/ (Carlton 1991: 236, Stieber 1973: 109-110, Rospond 1971: 115-117).

Glide insertion

Another, rather rare change, is the depalatalisation from /r^j/ to a sequence of /r/ and /j/ in intervocalic position, called "glide insertion". This sound change took place in Slovene, some Ukrainian dialects, and Lower-Sorbian (Greenberg 2000: 95-96, Carlton 1991: 311-312, Jakobson 2002: 216, Stadnik 2002: 149). Although /l^j/ and /n^j/ also underwent depalatalisation through glide insertion intervocalically in Slovene, this change was posterior to /r^j/ > /rj/ Carlton (1991: 311-312). In addition, Broch (1910: 158-159) observes that he perceived the realisation of /l^j/ and /n^j/ as /jl/ and /jn/, i.e. with a glide usually inserted before these consonants in some dialects of Slovene. However, /r^j/ was always realised as /rj/.

Summary

In sum, the opposition between rhotics seems to be less stable than between laterals. If a language loses the contrast between palatalised and plain consonants, rhotics (among with labials) often lead this change. In Slavic languages, palatalised rhotic underwent three types of change: loss of secondary gesture and a subsequent merger with its plain counterpart, spirantisation, or glide insertion (Kavitskaya 1997, Filin 1972). Usually, the opposition between laterals does not neutralise; instead, both palatalised and plain laterals experience a phonetic change: the palatalised lateral might change to a plain lateral after the velarised [ɫ] vocalises into [w] (like Polish, Upper Sorbian, some Russian dialects; Carlton 1991, Avanesov 1949: 169-171).

1.3.5 Palatalised rhotics in other language families

Several languages from other linguistic families present secondary palatalisation as phonemic feature, e.g. Tatar (Turkic family), Khalkha Mongolian, Buryat (Mongolic family) or Karelian (Uralic family, Stadnik 2002). Estonian and Scots Gaelic also have palatalised consonants in their phonemic inventories. Estonian lost the contrast between palatalised and plain rhotics, unlike between palatalised and plain laterals. While Ariste (1943: 43) still observes /r^j/ in spoken Estonian at the beginning of the XX century, studies from 50-60s provide controversial data. For some authors, /r^j/ is still a phoneme of Estonian (Liiv 1965), for others it is no more part of the consonantal system (Lehiste 1965, Eek 1973).[10] Scots Gaelic does not contrast between /r/ and /r^j/ in word-final position and before front vowels any more (Stadnik 2002: 148). The contrast between laterals is still active in all positions.

Also Proto-Tupían probably had plain and palatalised taps in its inventory, where the latter changed posteriorly to a retroflex fricative /ʐ/ (Rodrigues and Cabral 2012: 509). However, there were presumably no laterals in this language.

Shevelov (1964: 217) states that Rumanian treated lj-, nj-, rj-clusters in a similar way to Proto-Slavic. The author claims that all three clusters changed to palatalised consonants at an intermediate historical stage. But while lj- and nj-clusters changed later to /j/, rj-clusters lost the palatalisation and merged with plain /r/.

[10] Thanks to Pire Teras for providing this information.

1.4 Sound change

One of the most intriguing issues in historical linguistics concerns the question of why and how the sound change takes place. It is well known that human speech displays much variation and no two utterances, even by the same speaker, are identical (Ohala 1993: 239). At the same time, speakers should not change their pronunciation drastically if they want to be understood by other speakers of the same linguistic community. At which moment and why, then, did, e.g. the Latin speakers from the Iberian Peninsula start to deviate in their pronunciation of the word FILIUM 'son' so that after several centuries, all speakers of modern standard Spanish pronounce it as /ixo/?

The long-lasting interest in sound change, which was especially initiated by Grimm's studies on Proto-Indo-European language (Hock and Joseph 1996: 114-118), still persists, as the existence of two regular and independent workshops on sound change demonstrates.[11] One of the attractive aspects in studying sound change lies in the fact that it can (and should) be investigated from very different directions such as preconditions of sound change, actual triggers of a given sound change, its spread through the lexicon and through the community (see Ohala 1993: 238). While some researchers limit their investigation to only the initiation of sound change (Ohala 1993, Recasens et al. 1997, Browman and Goldstein 1992, Garrett and Johnson 2013, Blevins 2004) or to its propagation in the community (Labov 1963, Hale 2003), other researchers highlight the importance of combining the two directions in one model (Harrington et al. 2016).

Nevertheless, the most broadly investigated direction is the analysis of phonetic preconditions of sound change. While first attempts to explain sound change made the speaker responsible for it (Paul 1995, Martinet 1952), Ohala was practically the first one who consistently developed the idea that the listener plays the crucial role in sound change (Ohala 1981, 1989, 1993, etc.). Some theories like H-and-H-theory (Lindblom et al. 1995) intend to combine speaker's and listener's role in one model. However, the discussion as to whether the crucial change occurs in the articulation or in the perception continues to be a hot topic (see e.g. the recent article from Bybee 2015 criticising the perception-based account).

[11]International Workshop on Sound Change (WSC) and Workshop on Sound Change which usually takes place in Salamanca, Spain.

1.4.1 Preconditions of sound change: Articulation- vs. perception-based accounts

The first attempts to explain why sounds change over time consisted in attributing the main role to the speaker. A very common opinion stated that speakers would change their pronunciation in order to make some sounds "easier" to be articulated. To consider the speaker as a driving force in sound change has a very long tradition (Osthoff and Brugman 1967, Paul 1995, Martinet 1952). More recent articulation-based theories began to disregard the teleological idea that sound change has a goal.

The main idea in articulation-based accounts is that sounds influence each other due to coarticulation. As a result, the acoustic outcome is ambiguous and leads the listener to fail to recover the intended sound. On the other hand, the perception-driven account claims that the listener is the primary source of sound change. For Ohala (1981, 1989, 1993), the articulation is necessarily always ambiguous but the listener usually correctly recovers the produced sound. Sound change occurs when the listener fails to recover the produced sound or believes he or she hears a sound which was not intended by the speaker but is rather due to the coarticulation.

Thus, in the theories about the initiation of sound change, two main directions can be traced. Both directions agree that sound change happens because of variation in speech. As Chitoran (2012: 312) states,

> Where they differ is in determining the relative importance of a particular type of variation: the phonetic variation inherent in the signal produced by the speaker (production-oriented change), or the variation perceived by the listener (perception-oriented change).

In the following, I will describe the articulation- and perception-based theories - Articulatory Phonology, DAC-model, and Ohala's perception model - in more detail.

Articulatory Phonology

The framework of Articulatory Phonology has been developed to describe the phonological representation of sounds by embedding the phonetic information (Browman and Goldstein 1986, 1989, 1992, 1995, 2000, see detailed overviews in Bombien 2011, Peters 2015, etc.), but has also been extended to the analysis of sound change (Browman and Goldstein 1991, Beckman et al. 1992, Mowrey and Pagliuca 1995, Bybee 2002, 2015). Articulatory Phonology operates with basic units called *gestures*, which are, simultaneously, minimal abstract phonological units and concrete phonetic realisations. *Gestures* are specified by a small definite set of *tract variables*:

- lip protrusion (LP)
- lip aperture (LA)
- tongue tip constriction location (TTCL)
- tongue tip constriction degree (TTCD)
- tongue body constriction location (TBCL)
- tongue body constriction degree (TBCD)
- velic aperture (VEL)
- glottal aperture (GLO)

which involve related physical articulators (upper and lower lips, tongue tip, tongue body, velum, glottis, and jaw). The *gestures* are combined into greater constellations to form words or utterances. An utterance is specified by a *gestural score*, which specifies the activation of appropriate tract variables for this utterance, the target, stiffness (i.e. frequency of oscillation) and damping of the articulators (Browman and Goldstein 1992: 23-24).

The spatial and temporal distribution of the activated articulators or gestures is also important in this model. Thus, an aspirated plosive /t^h/ in English differs from an unaspirated /t/ in Spanish in the relative timing between tongue tip gesture and glottis opening: while they are articulated simultaneously in the latter, the glottis stays open (or wide) longer with respect to the tongue tip in the former. The advantage of this way of thinking is that the AP-framework does not need an extra label for aspiration, but is able to represent it just by specifying the relative timing between the two involved gestures.

Thus, a large number of phonetically different sounds can be described or specified by the limited set of parameters. Two gestures can be differentiated from each other in the set of involved tract variables (which encode both constriction location and constriction degree, corresponding to articulation place and manner); in the relative timing between these tract variables; and also in target, stiffness, and damping of the articulators. It should be kept in mind that stiffness is defined as frequency of oscillation (in Hertz) rather than as muscular activity (Browman and Goldstein 1990b: 6). Since stiffness involves relative velocity of the articulators, there have been several attempts to use this parameter to differentiate between natural classes of sounds (Browman and Goldstein 1992: 26; see Chapter 4 for more discussion on stiffness).

The timing between tract variables and gestures is of a greater relevance, not only for separate sounds and languages, but also at the syllabic level. In the AP model (Browman and Goldstein 1986, 1988) it is assumed that the syllable-initial CV-sequences present tighter and more stable connections (they are organised in-phase) than the syllable-final VC-sequences (anti-phase). Chapter 3 discusses the implications of timing in more detail.

Articulatory Phonology and sound change

The framework of Articulatory Phonology has been used to explain many sound changes (Browman and Goldstein 1989, 1991, Beckman et al. 1992, Bybee 2002, etc.). In this framework, two processes are claimed to be responsible for many sound changes: reduction of gestural magnitude (both in space and time) and/or gestural overlap (Bybee 2015). These two processes have been observed in casual or fast speech (Browman and Goldstein 1990b: 17) and applied to explain many processes of sound change such as weakening, assimilation or segment deletion (Browman and Goldstein 1991).

Two sound change processes should be presented here in more detail: segment deletion and insertion. The AP predicts that the gestures are always activated during the production of a particular sound. But what happens at faster speech rates is that they are reduced in space and time and or overlap more than at slower speech rates. As a result, the acoustic outcome may create the perception that particular sounds are realised more weakly or are omitted. For example, in a faster speech, the release of /t/ may be obscured by the overlapping gesture for the following /m/ in the sequence *perfect memory*. Although the tongue tip gesture for /t/ is articulated, it is acoustically masked by the following /m/. As a consequence, the listener may interpret /t/ as omitted (Browman and Goldstein 1990b: 364-365). Beckman et al. (1992) applied this model to explain many apparently unrelated sound changes like vowel reduction, consonant lenitions or insertions, voicing of stops and fricatives etc.

In contrast, segmental insertion may occur as the acoustic result of the variation in gestural overlap (Browman and Goldstein 1992: 327). Examples of such sound changes can be seen in English nasal-fricative sequences in words like *something*, where an epenthetic stop is inserted. The explanation for this sound change can be due to the relative timing between the velic gesture in the nasal and the following fricative. It can happen that the velic gesture lowers or rises earlier than it should due to the following oral consonant. As a consequence, a short part of a denasalised bilabial constriction can occur between the nasal and the fricative, which could be interpreted as an oral bilabial plosive /p/.

Bybee (2002, 2015) incorporates the two mechanisms proposed by Browman and Goldstein in her model of sound change. For Bybee (2015: 467), speech is "automation of repeated behaviours", where gestures necessarily present the reduction in magnitude and increasingly overlap with an increased proficiency of language. As a result, the sound change affects the highly frequent words first because they are used more often (see Bybee 2002 for empirical evidence of both gradual phonetic and gradual lexical diffusion of sound change). That means that the speaker changes his or her pronunciation while he or she speaks (the sound change happens online, Bybee 2002). The sound change is thus due to automation of articulation and not to the false previous perception (Bybee 2015).

DAC-model

The DAC-model (Degree of Articulatory Constraint) has been developed to account for the coarticulation resistance of sounds (Recasens et al. 1997, Recasens 2007) and extended to studies of sound change (see Recasens 2014). The articulatory constraint of a speech sound is mainly defined as "the degree of involvement of the tongue dorsum in closure or constriction formation" (Recasens et al. 1997: 544). The DAC-model predicts that the more complex the articulation of a consonant or vowel is (especially in the tongue dorsum), the more resistant it is to and the greater will be its influence on surrounding speech sounds. It is not to say that articulatorily complex speech sounds will not be influenced at all. Rather, the sound will allow less variation in the part which is directly involved in its production but will present more variation in the speech organ which does not participate directly in its articulation. For example, the velarised [ɫ] would be highly constrained in the tongue dorsum because it is the most important part in its articulation. This means that the tongue dorsum in the velarised [ɫ] should be highly resistant to coarticulation from adjacent sounds and at the same time execute prominent effects on other sounds (Recasens 2013a). At the same time, the tongue tip in /ʎ/ could present more variation than the tongue dorsum because the former is not directly involved in its production (Recasens 2013b: 2).

Based on several empirical studies, especially on Catalan and Spanish, Recasens and colleagues (1997) proposed a scale on which the phonetic segments are grouped according to their degree of articulatory constraint. In agreement with this scale, the consonants and vowels can be divided in three groups (from the least to the most constrained):

(1) /b/, /ə/ > (2) /a/ /t/, /n/, /s/ > (3) /ɲ/, /ʃ/, /k/, /i/, /ɫ/, /r/

Although the scale is based primarily on the data from Catalan and Spanish sound systems, the authors suggest that it could potentially be applied to other languages, since it is based on production data. However, Recasens et al. (1997) claim that some sounds could differentiate in the same group and more research is needed in order to determine whether the scale should be more differentiated and whether it can be applied to other languages.

As is shown in the scale, velarised laterals and alveolar trills are the most constrained sounds, at least in Romance languages (Recasens 2013a). Some studies showed that alveolar trills and velarised laterals are stronger than alveolar taps and "clear" laterals, respectively (Recasens and Pallarès 1999, Recasens and Espinosa 2005, Recasens 2012a). At the same time, alveolar trills (like in Spanish or Catalan) seem to be even more constrained than velarised laterals, because the former require very precise articulatory conditions in order for the trilling to occur (Recasens 2013a). In alveolar trills, the whole tongue is highly constrained.

Recasens applied the DAC-model to describe and explain many sound changes in Romance languages (Recasens 2014). He demonstrated that the degree of relative constraint of a given sound can potentially predict how resistant this sound would be against the influence of other sounds, which could be the possible outcome due to coarticulation and also the directionality of the influence.

Perception-based account

While speaker-based theories like Articulatory Phonology or the DAC-model see the origin of sound change in the articulation, over the years, Ohala (1981, 1989, 1993, 2012) has been developing the idea of the ultimate importance of the listener in sound change. Ohala (1993) highlights the fact that the variation in speech is omnipresent. But he claims that, most of the time, listeners are aware of coarticulation. The listeners know that sounds may be highly reduced or overlap with other sounds in connected speech, and, thus, always perceptually normalise for this. This is the reason why the sound change happens extremely rarely.

However, a mini sound change may occur if the listener fails to normalise for speech. Ohala (1993) distinguishes mainly between two types of sound change: hypo- and hypercorrection. For Ohala (1993: 247-248), the phonological nasalisation of vowels which happened, e.g. in French, is an example of sound change due to hypocorrection. Vowels surrounded by nasals present some phonetic nasalisation. Listeners usually know this and in most cases rule it out correctly and interpret the vowels as oral. But the listeners may eventually interpret the phonetic nasalisation as planned by the speaker. As a result, the vowels would acquire the distinctive feature of [+/−] nasalised, while the coda nasals would get lost in these contexts.

Another type of sound change, which happens due to hypercorrection, may occur when the listener interprets a phonological quality of a sound as a result of pure coarticulation. In such cases, she or he normalises "too much". For example, in the Latin word /kʷiŋkʷē/, both velar plosives were originally labialised (Ohala 1993: 250-251). With the course of the time, however, the first /kʷ/ lost the labialisation. Ohala explains this sound change as follows: the listener perceived the labialisation on both consonants and the vowel in-between. She or he would get confused by the fact that the labialisation is extended over the whole word. The listener would think that only one of the consonants actually might have phonemic lip-rounding, while another one has it just due to coarticulation. As a result, the listener would interpret the word as */kiŋkʷē/ (which later changed to Italian /ʧiŋkʷe/, Ohala 1993: 250). Ohala's explanation will also be applied to the data in order to explain the sound change which happened to palatalised rhotics.

1.4.2 The present study

The present study intends to analyse the articulation of palatalised rhotics in Russian and to compare it to plain rhotics and to palatalised and plain laterals. As has been described in the previous chapters in more detail, Proto-Slavic palatalised rhotics have three reflexes in the modern Slavic languages: they either lost the secondary gesture and fell together with plain trills, were broken up into /r/ and /j/ through glide insertion, or changed to fricatives. The following chapters analyse the articulation of palatalised rhotics, by paying special attention to these three sound changes. In Chapter 2, the articulatory difference between palatalised and plain rhotics is analysed and compared to laterals, addressing the first type of sound change. In Chapter 3, the timing between the primary and secondary gestures is investigated in more detail. This analysis intends to shed light on glide insertion. In Chapter 4, the influence of the secondary gesture on the tongue tip is analysed in order to investigate the change from /rʲ/ to /r̝/ (spirantisation). Particularly, the tongue tip velocity and stiffness in palatalised and plain rhotics and laterals are compared. Chapter

5 closes the present study with a general conclusion.

Chapter 2

Stability of articulatory contrast between palatalised and plain rhotics and laterals

2.1 Introduction

Although rhotics and laterals belong to the same phonological class of liquids, the contrast between palatalised and plain rhotics has been neutralised more often than between laterals, cross-linguistically (Kochetov 2005, Hall 2000b). Three main outcomes of sound change affecting palatalised rhotics are: contrast reduction (complete or partial merger between /r^j/ vs. /r/ into /r/, Belarusian, Serbo-Croatian, Slovak, Ukrainian, etc.), glide insertion (the change from /r^j/ into /rj/, Slovenian, some dialects of Ukrainian), or spirantisation (the change from /r^j/ into /r̝/ in Czech or /ʒ/ in Polish; Carlton 1991, Kavitskaya 1997, Kochetov 2005). The present chapter deals with the former and the most common sound change: the contrast reduction between /r^j/ and /r/. The opposition between palatalised and plain laterals seems to be more stable. Laterals also have been subject to change in several Slavic languages, but, unlike rhotics, the former usually do not merge. The phonological opposition either remains active (as in Belarusian), or both consonants undergo sound change. In Polish, for instance, the velarised lateral changed into /w/, while the palatalised lateral lost the palatalisation feature (Stieber 1973: 110-112, Rospond 1971: 116-117).[1]

[1] Even in cases when the contrast between palatalised and plain laterals was finally lost, this usually was dated posterior to the change in rhotics (e.g. word-finally in Slovene, Carlton 1991: 312).

The main reason behind this asymmetry, it has been suggested, lies in the articulation. Palatalisation and trilling are claimed to be two incompatible modes of articulation (Ladefoged and Maddieson 1996: 221, Kavitskaya 1997), which have negative consequences for palatalised rhotics. On the one hand, the articulatory difference between palatalised and plain rhotics seems to be smaller than between palatalised and plain laterals (Kochetov 2005). On the other hand, the timing between the primary and secondary gestures is simultaneous in palatalised laterals but sequential in palatalised rhotics, where the tongue body is delayed with respect to the tongue tip gesture (Kochetov 2005, Stoll et al. 2015; see Chapter 3 for more details). Since the main acoustic difference between palatalised and plain consonants lies in the F2, which corresponds to the tongue height, a smaller articulatory difference and a delayed tongue dorsum raising gesture could lead more easily to a confusion between /r/ and /r^j/ than between /l/ and /l^j/.

The word-final position and the position before front vowels have been recognised as the environments where the contrast reduction or other phonological changes are more prone to occur (Hock 1991: 80-96, Ohala and Kawasaki 1984, Padgett 2001). These sound changes have often been attributed to articulation, i.e. to the gestural reduction in word-final position (Hock 1991: 96) or to a strong articulatory influence of high front vowels (Flemming 2013: 103). The underlying assumption is that the smaller articulatory difference in such contexts will render a less stable phonological opposition, diachronically (following Kochetov 2002, 2005, Flemming 2013, Steriade 1997). In other words, articulatory and/or acoustic proximity will be the main reasons behind the contrast neutralisation (Recasens 2014: 184). The aim of the present study is, thus, to analyse whether the often observed contrast neutralisation between palatalised and plain rhotics can be explained by their articulatory properties.

2.1.1 Gestural reduction in word-final position

Diachronic evidence for word-final contrast neutralisation

A substantial body of research work on historical linguistics has shown that sounds tend to undergo changes more often in word-final than word-initial position (Hock 1991, Ohala and Kawasaki 1984, Hooper 1976: 199). The most typical sound changes affecting word-final position are assimilation, weakening, loss, etc. (Hock 1991: 95-96, Honeybone 2008, Cser 2015: 199-201, Krakow 1999). These processes have in common that they are often interpreted as “lenition” processes (Harris 2009). In contrast, word-initial position has been described in phonology as a strong position, where the sounds change less often than in word-final position (Fougeron 1999). Sound change processes which affect sounds in this position are typically related to "strengthening" processes (Cser 2015: 201, Hooper 1976: 199, Harris 2009). The contrast between palatalised and plain rhotics was lost in word-final position in Ukrainian, Bulgarian, Slovene, Upper Sorbian, and Scots Gaelic (Carlton 1991, Stadnik 2002: 148; see Chapter 1 for more detail).

Phonetic causes of final neutralisation

Word-final contrast neutralisation has often been attributed to gestural reduction. Many empirical studies have shown that consonants differ in their articulation depending on whether they occur in initial vs. final word-position (see overviews in Krakow 1999, Fougeron 1999, Mok 2010, Solé 2010, Browman and Goldstein 1995, Byrd 1996b). Krakow (1999) presented a rather broad description of studies on articulation and inter-gestural timing in consonants depending on their position in the word. The author concluded that there is a substantial body of empirical evidence that coda consonants are articulatorily "weaker" elements, as compared to onset consonants (Krakow 1999: 48). Overall, coda consonants present less tight articulatory gestures and extensive variability or less acoustic duration (Krakow 1999: 25).

Many studies have shown that coda consonants are more prone to lose the primary than the secondary articulation (Browman and Goldstein 1995: 26). For example, laterals usually present reduced tongue tip gesture in word-final position (see references in Krakow 1999). Giles and Moll (1975) demonstrated that the tongue tip contact in laterals was sometimes absent in word-final position, especially at a fast speech rate, but never in word-initial position. Browman and Goldstein (1995) confirmed previous findings about the tongue-tip reduction in word-final position for English laterals. They showed that, at least in English, there is a considerable gestural reduction in syllable-final position, measured as reduction in absolute vertical position.

Less attention has been paid to the tongue dorsum gesture in different word positions. The analysis of tongue dorsum in coda velarised laterals in English indicated that the tongue dorsum is reduced less than the tongue tip (Lin et al. 2014). Hsieh and Goldstein (2015) state that "Gick (2003) found that all gestures of syllable-final [j] and [w] exhibited final reduction compared with word-initial onglides a property usually found in coda consonantal gestures." Recasens and Espinosa (2010) give examples for depalatalisation of coda palatal nasals and their subsequent merger with plain nasals in Romance languages.

The authors attributed the contrast neutralisation between coda palatal and plain nasals in some Spanish varieties to a reduced dorsum gesture in the former, although their empirical analysis could not support this hypothesis. Concerning the secondary palatalisation, Kochetov (2006a) investigated palatalised and plain plosives /p/ and /p^j/ in syllable-initial and -final positions in Russian and found that the tongue dorsum in syllable-final /p^j/ was reduced (by measuring the vertical position). In his analysis of several Russian consonants, Kochetov (2009: 66-67) mentioned that the tongue dorsum generally presented gestural reduction in syllable-final position.

On the other hand, some findings make us wonder whether gestural reduction is indeed always at work in word-final position. Krakow (1989) found that syllable-final nasals in English presented a more lowered velum than in syllable-initial position. Fougeron and Keating (1997) found differences in onset and coda alveolar nasals, which they attributed to initial strengthening rather than to word-final gestural reduction. The strength of the consonants increased with the increase of prosodic organisation (word initial vs. phrase initial, etc.). However, by comparing the consonants in the same word-domain (word-initial, medial, vs. final) the authors found only little evidence of the gestural weakening of coda consonants (in one out of three speakers).

Although gestural reduction was not the main goal in their study, Gick et al. (2006) mention that they did not observe gestural reduction in velarised coda laterals (as compared to initial position) in Serbo-Croatian. The authors attributed this finding to the fact that Serbo-Croatian presents a phonological opposition between palatalised and plain laterals. As a consequence, the gestural organisation between the tongue tip and tongue dorsum might be tighter and the gestures are not reduced as easily as in the case of languages without such phonemic opposition. In an acoustic study, Iskarous and Kavitskaya (2010) also found no traces of reduction of the palatalisation gesture in word-final palatalised trills in Russian.

To summarise the data presented in this section, the consonants usually do exhibit spatial and/or temporal reduction in word-final position, although there are studies which presented little or no evidence for this hypothesis. While it seems to be the case that the tongue tip gesture is often reduced in word-final position, the tongue dorsum gesture seems to be more resistant to the influence of word-position. Nevertheless, the results are mixed even for languages with phonemic contrast between palatalised and plain consonants (compare e.g. Kochetov 2006a vs. Gick et al. 2006 on Russian and Serbo-Croatian). It is hypothesised that the tongue dorsum in palatalised consonants is probably less prone to be reduced because of the phonological opposition which has to be maintained (as compared to languages without the phonological opposition). Nevertheless, palatalised rhotics will probably show more tongue dorsum variation. Since the problem of palatalised trills lies in the antagonistic requirements associated with their articulation, it is expected that this conflict will somehow be teased apart every time there is a possibility to do so. While palatalised laterals should present no tongue dorsum gestural reduction in coda position, palatalised rhotics would have lower a tongue dorsum as compared to onset position.

2.1.2 Influence of high vowels

Diachronic evidence

It has been observed that high vowels, especially high front vowels, act as triggers in sound change processes more often than low vowels do (Recasens 2014: 106, 142). Vennemann (1988: 8) considers low vowels the weakest sounds on the Universal Consonantal Strength scale. High front and back vowels trigger secondary articulation like palatalisation, velarisation, or labialisation (Hock 1991: 73-77, Recasens 2014). High front vowels trigger umlaut, i.e. the raising of preceding low vowels (Hock 1991: 66-68, Garrett 2015). High vowels, unlike low vowels, trigger vocalic harmony in Basque (Egurtzegi 2013: 130-132). At the same time, high vowels (especially high front vowels) present high coarticulation resistance (Recasens et al. 1997). In many languages, the contrast between palatalised and plain consonants was neutralised before front vowels, while it still remains active before low vowels (Stadnik 2002). In Slavic languages, the contrast before front high vowels has been lost in Bulgarian and some dialects of Russian (see Chapter 1 for more details).

Articulatory reasons for the contrast neutralisation before high vowels

Contrast neutralisation before high front vowels usually affects all consonant phonemes in a language equally; there is not necessarily a bias for rhotics. Nevertheless, the opposition between /r^{j}/ and /r/ may be especially prone to impairment in the context before both /i/ and /u/, unlike before /a/. The reasons for that might be, first, the general instability of palatalised rhotics and, second, a smaller articulatory difference between /r^{j}/ and /r/.

High vowels are considerably constrained because they imply an active tongue dorsum raising and, thus, exert more influence on neighbouring sounds (Recasens et al. 1997). In contrast, the articulation of low vowels depends more on the jaw lowering than on an active tongue dorsum movement (see Recasens 1999 and references therein). The assumption is, thus, that the high vowel greatly overlaps with the preceding plain consonant. As a consequence, the distance between palatalised and plain consonants is smaller in the context of high than in that of low vowels (see Flemming 2013: 103 for similar explanation).

Predictions in AP and DAC-model

Articulatory Phonology

The AP framework states that the two main causes for sound change are gestural reduction and increased gestural overlap (Browman and Goldstein 1991). Thus, this model predicts that the contrast neutralisation in word-final position would be due to the tongue dorsum reduction in the palatalised consonant (both /r^j/ and /l^j/). The AP would also state that an increased overlap between a plain consonant and the following high vowel will result in a smaller articulatory difference between palatalised and plain consonants in this context. The reason for this is that both palatalised and plain consonants would present a more or less raised tongue dorsum due to the palatalisation and to the influence of a high vowel. This framework does not predict different behaviour for different vowels and consonants. Thus, this claim should hold for both rhotics and laterals in the context of both /i/ and /u/. As a result, a smaller articulatory difference between the palatalised and plain consonants would lead to a smaller acoustic difference between them. Since the distance between the rhotics is already small compared to laterals, the distance will be even smaller under unfavourable conditions like word-final position or before high vowels.

DAC-model

The explanation for the present sound changes will be similar in the DAC-model to that exposed for the AP: the gestural reduction in word-final position (see Recasens and Espinosa 2010a) and increased overlap with the following high vowel. However, the DAC-model differentiates between sounds in the degree of their coarticulatory resistance or aggressiveness. Although word-final consonants would generally be reduced, rhotics may be quite resistant to the influence of this phonetic context. Particularly, Recasens showed that rhotics, especially trills, were not reduced in word-final position in Eastern Catalan (Recasens and Espinosa 2007). Thus, the DAC-model would predict that, on the one hand, both /l^j/ and /r^j/ may not be reduced in word-final position because both sounds imply a quite complex articulation. On the other hand, the DAC-model gives the same value to rhotics and high vowels /i/, but laterals are less constrained than rhotics (Recasens 2013a). Thus, /r^j/ may present less or no traces of gestural reduction word-finally because this sound is very resistant to coarticulation, compared to /l^j/.

The high vowel is supposed to exert a great influence on neighbouring consonants and to overlap with them considerably. Although both vowels /i/ and /u/ involve an active tongue dorsum raising, /i/ is probably more aggressive and presents more overlap with the preceding consonant than /u/ (Recasens 1999, Recasens 2012b). The reason behind this is that the tongue dorsum plays an important role in the production of liquids: the articulation of liquids, especially trills, requires a quite fixed and retracted tongue dorsum. But the high front vowel poses an additional effort on it, because it implies active tongue dorsum raising (which does not occur with low vowels). It could by hypothesised that the distance between tongue dorsum positions in /r^j/-/r/ and /l^j/-/l/ pairs is smaller before high vowels than before low vowels because plain consonants will be quite influenced by the high vowel. Admittedly, the plain rhotics are very resistant to the vocalic influence (Proctor 2009 for Russian and Spanish, Recasens 2013a for Spanish), but it is not true that trills are invariable at all. Iskarous and Kavitskaya (2010) demonstrated that Russian palatalised and plain rhotics also present some variability.

In sum, it is expected that the distance between palatalised and plain liquids will be smaller in the context of high vowels /i/ and /u/ due to the increased overlap between the plain consonant and the following high vowel, compared to /a/-vowel. Although both /i/ and /u/ imply the raised tongue dorsum gesture, the overlap should be greater and the distance smaller before /i/ than before /u/. In addition, the influence of high vowels should be greater in the case of laterals than rhotics.

2.1.3 Speech rate

Another factor which was chosen for the analysis of the articulation of palatalised rhotics is the influence of speech rate: normal (here referred to as slow speech rate) and fast speech rates, which correspond to hyper- vs. hypo-articulated speech. Fast speech rate may be responsible for many reduction processes (e.g. final -s in Spanish, File-Muriel and Brown 2011). Several previous studies have used this technique to elicit more vs. less careful speech (Gay 1978, Slis and Van Lieshout 2016). Fast speech rate has been reported to exert influence on the articulation of sounds. Giles and Moll (1975) found out that the tongue tip in word-final laterals was more reduced at faster speech rate. Hertrich and Ackermann (1995) claim that there was less coarticulation at slower speech rate. The framework of Articulatory Phonology states that the fast speech rate is responsible for gestural reduction (Browman and Goldstein 1991: 324). Thus, a greater tongue dorsum reduction at faster speech rate in both palatalised rhotics and palatalised laterals is expected.

2.2 Predictions and hypotheses

This chapter has two goals. The first is to investigate whether the articulatory difference (measured at the tongue dorsum position) between palatalised and plain rhotics and laterals varies depending on their position in the word. The second is to determine if any such variation in articulatory difference is due to a local weakening of secondary gesture in palatalised consonants and to a strong influence of high vowels on /r/.

The assumption behind the present analysis is the following: since trilling and palatalisation are incompatible (Ladefoged and Maddieson 1996: 221, Kavitskaya 1997) and the articulatory difference between /r^j/ and /r/ (manifested mainly in the tongue dorsum position) is relatively small (4 mm vs. 10 mm between laterals, Kochetov 2005), I expect this difference to be negatively influenced in certain contexts. First, due to the cross-linguistic tendency to gestural reduction in word-final position, I expect the tongue dorsum to lower in /r^j/ in coda position. Second, the high front vowel would overlap considerably with the preceding plain rhotic. The fast speech rate will probably also influence the articulatory distance negatively, also leading to a tongue dorsum reduction in /r^j/. Under these conditions, the articulatory distance between palatalised and plain rhotics will be reduced, which would provide poorer cues for the differentiation between palatalised and plain rhotics.

Thus, the hypotheses to be tested here are the following:

H1: The articulatory difference is smaller between rhotics than between laterals (as already shown in Kochetov 2005).

H2: The articulatory difference between palatalised and plain rhotics and laterals is smaller in word-final position as compared to initial/medial positions.

H3: The articulatory difference between palatalised and plain rhotics and laterals is smaller before high vowels than before low vowels. But since the articulatory difference between /r^j/ and /r/ is already quite small, the negative effect will be greater in rhotics than in laterals.

H4: Palatalised rhotics present greater tongue dorsum variation and reduction because of the articulatory conflict between trilling and palatalisation as compared to palatalised laterals.

H5: The articulation is influenced by speech rate, especially in palatalised rhotics: the articulatory difference between /r^j/ and /r/ is even smaller at a fast than at a slow speech rate.

2.3 Method

2.3.1 Participants

In order to address the hypotheses, an articulatory experiment using Electromagnetic Articulography (EMA, AG501, Carstens Medizinelektronik, GmbH) with six native Russian speakers (5 female, 1 male; age: 25-35) was performed. All the subjects grew up in a Russian-speaking country and were monolingual in Russian until at least 17 years of age. They were recruited at the Ludwig Maximilian University of Munich and had spent two to fifteen years in Germany at the time of recording. No speech or hearing disorders were reported. A pilot study was performed initially with the author as the first informant in order to check whether the experiment design was adequate. After the data analysis of the pilot study, the speech material was slightly modified (See Appendix A for the design of the main study). The data from both pilot and main study will be analysed here. The speakers were unaware of the purpose of the study, except the informant V1 (the author). Before the recordings, all participants read a detailed description of the experiment procedure and potential risks in the Russian language. The participants were explicitly informed of their right to interrupt the experiment at any time.

2.3.2 Speech material

The participants pronounced real words embedded in a carrier sentence. Target words contained the consonants /r/, /r^j/, /l/, /l^j/ and the stressed vowels /a/, /i/, /u/. When possible, two-syllable words were chosen. Different word domains were selected: word-initial, -medial, and -final positions. In word-initial and -medial positions, the stressed vowel /a/, /i/ or /u/ followed the liquid; the preceding vowel was an unstressed /a/-vowel.[2] In word-final position, the reverse was true. Since the present chapter deals with the difference between final and non-final positions, the word-initial and word-medial positions were collapsed into one group. The participants were asked to read the sentences at a slow and a fast speech rate alternately. The target words, the carrier sentences, and translation from the main study are presented in Appendix A.

In order to minimise the articulatory influence from surrounding consonants, target words and carrier sentences with plain nasal or oral labial consonants were chosen whenever possible (non-palatalised alveolar consonants otherwise). Consequently, the target words

[2]Note that in Russian, non-stressed vowels undergo substantial reduction.

were not controlled for word frequency.

2.3.3 Recordings

The participants were recorded by means of EMA at a data rate of 1250 Hz.[3] EMA coils were attached to the upper and lower lips, the jaw, and the tongue. The tongue-tip (TT) sensor was placed a few millimetres from the tongue tip. The tongue-back (TB) sensor was placed as far behind as participants could tolerate, approximately 6 cm from the tongue tip. The tongue-dorsum (TD) sensor was placed between the two other sensors. Additional coils for head movement correction were located above the upper incisors, on the bridge of the nose, and behind each ear. The sensors were attached with a glue to the tongue and face. The sensors on the tongue were additionally reinforced with medical cement in order to prevent them from becoming detached during the recordings. The articulatory data were sampled at a frequency of 40 Hz.

In order to habituate the informants of the main study with the sensors, they had to participate in two sessions. During the first session, the informants were asked to speak freely without being recorded, in order to insure they were comfortable with the coils on the tongue. The data presented here were recorded during the second session which took place a few days later. The overall time the participants spent in the lab amounted to 2.5-3 hours for two sessions. The participants were paid 25, Euros per hour for their efforts.

Acoustic data were recorded at the same time with a microphone and were sampled at 25600 Hz.[4] The speech material was presented to the speakers for reading ten to twenty times in randomised order. If the participants mispronounced the target word, they were told to read the sentence again immediately. The sentences were integrated into a Power Point presentation and were displayed on a monitor in Cyrillic script.

The speech material was presented to the speakers for reading in blocks consisting of 36 target sentences in randomised order preceded by one dummy sentence. The participants were asked to read the sentences at a slow and a fast speech rate alternately, by changing the speech rate after each block. A posterior statistical comparison of word durations showed a significant difference between slow and fast speech rates. The participants were allowed to stop and drink after each block. Participants were also recorded by means of a video camera for possible later questions. The recordings took place in an anechoic room

[3]Due to the EMA software actualisation in the period between the pilot and the main study, the data from the pilot were recorded at 200 Hz.

[4]The acoustic data from the pilot were sampled at 24000 Hz.

at the Institute for Phonetics and Speech Processing at the Ludwig Maximilian University of Munich in the summer of 2014.

The purpose of the experiment was to collect ten repetitions per trial and per speech rate; this way, the participants were expected to pronounce each target word a total of twenty times. However, in two sessions (participants V3 and V4), the experiment was interrupted earlier because the participants were tired. Thus, only 10 and 16 repetitions per target word were recorded for these participants, respectively. Approximately 2 per cent of the total data had to be disregarded for several reasons (e.g. due to false pronunciation or accentuation).

2.3.4 Data processing

The raw data were passed to Matlab for further normalisation and data correction. Acoustic data were manually labelled in Mtnew[5] and also automatically segmented with The Munich Automatic Segmentation System MAUS (Schiel 1999, Kisler et al. 2012), passed into the Emu-System (Cassidy and Harrington 2001, Winkelmann 2015, Harrington 2010) and manually corrected.

The labelling of physiological data was performed in Mtnew based on the tangential velocity (as a sum of vertical and horizontal velocities) of the articulators. Following articulators were labelled: tongue tip (for /r^j/, /r/, /l^j/, /l/), tongue back and tongue mid (only for /r^j/ and /l^j/). A gesture was labelled with the following landmarks:

Gesture onset,

Velocity onset (maximum velocity at onset),

Plateau onset (beginning of plateau),

Maximum constriction,

Plateau offset (end of plateau),

Velocity offset (maximum velocity at offset),

Gesture offset.

Maximum constriction and maximum velocity at onset and offset were detected easily. However, the onset and offset of a gesture and beginning and end of the plateau wwere more difficult to identify because of several zero crossing points. As a result, we chose their values as 20 percent threshold of the difference between two peaks in the velocity signal. Figure 2.1) shematically represents the positioning of the landmarks.

[5]Mtnew (Multichannel signal display) is a set of Matlab programs for processing of EMA-data designed by Philip Hoole. http://www.phonetik.uni-muenchen.de/~hoole/articmanual.

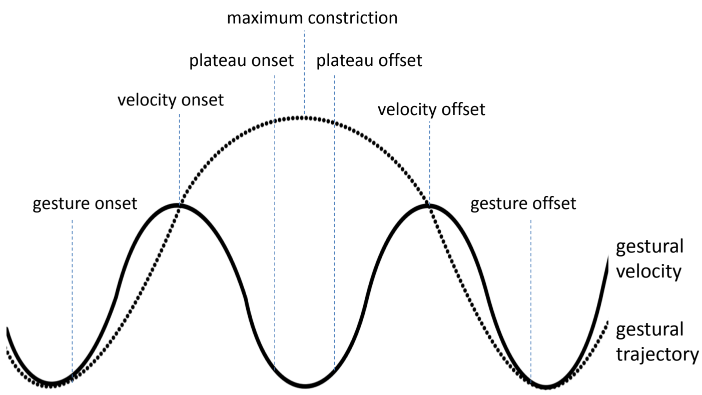


Figure 2.1: Schematic representation of landmark positioning.

2.3.5 Measurements

The main points of interest in the present chapter are, first, the articulatory distance between the palatalised and plain consonants of each pair (i.e. between /r^j/ and /r/ and between /l^j/ and /l/), measured in their tongue dorsum positions, and, second, the vertical tongue dorsum position in palatalised /r^j/ and /l^j/.[6]

The second coil (TD) was chosen in order to analyse the tongue dorsum positions in palatalised and plain consonants. It was possible to label the tongue dorsum gesture reliably only practically in palatalised /r^j/ and /l^j/ in the context of low vowels. The impossibility of labelling the tongue dorsum in all other cases was due either to the absence of the raising gesture in plain consonants, obviously, or to the presence of high vowels. In contrast, the tongue tip gesture could always be reliably identified. Thus, the **tongue-dorsum** position (TD coil) in the temporal **tongue-tip** plateau midpoint will be analysed in the present chapter.[7]

[6]Since a palatalised consonant is characterised by the tongue dorsum raising towards the hard palate, the tongue dorsum position is the primary cue for palatalisation (Ladefoged and Maddieson 1996: 363, Kochetov 2005). But the difference between palatalised and plain consonants might also lie in the tongue tip gesture (position and constriction duration), and acoustic duration (Kochetov 2005, Matusevich 1976, Iskarous and Kavitskaya 2010). The analysis of these factors is presented in Chapter 4.

[7]It should be kept in mind that the tongue dorsum gesture is delayed with respect to the primary gesture in rhotics, unlike laterals (Kochetov 2005, Stoll et al. 2015, see Chapter 3). However, this measure

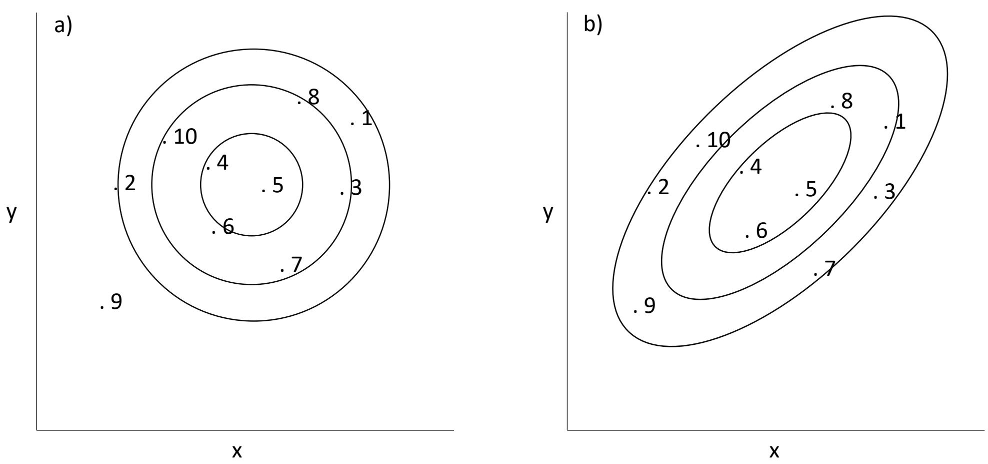


Figure 2.2: Two plots of the simulated data with Euclidean distance (left) and Mahalanobis distance (right) applied on them (following De Maesschalck et al. 2000: 4).

The articulatory difference between palatalised and plain consonants of each pair was measured with the Mahalanobis distance method. The Mahalanobis distance is based on the probabilistic distance between tokens in a two or more dimensional space (see De Maesschalck et al. 2000; also Brunner et al. 2011, Kartushina et al. 2015, Marin 2014 for applying this method to phonetic data). The Mahalanobis distance resembles Euclidean distance; both methods measure the distance from a token to the mean value of (other) tokens' distribution. But while the Euclidean distance does not presuppose any statistical distribution of the tokens, the Mahalanobis distance takes the covariation of the tokens into account (see Figure 2.2). Mahalanobis distance also presumes that the distribution of points that belong to a category follow a Gaussian distribution. Unlike Euclidean distance, the analysis of the data with Mahalanobis distance is based on elliptical rather than circular data distribution. In Figure 2.2, the graphs represent the distribution of the same data analysed with Mahalanobis (right) and Euclidean (left) distances. It can be seen that the Mahalanobis distance, unlike the Euclidean distance, adapts to the data distribution. Mahalanobis distance takes into account that, due to a non-normal data distribution, the distance from one token (e.g. token 9) to the mean is similar to the distance from another token (e.g. token 10) to the mean in terms of probability but not in the units of length (e.g. in mm).

Thus, the main advantage of the Mahalanobis distance over the Euclidean distance is that the former adapts to the data distribution. However (and still), if there is no correlation between the variables, the Mahalanobis distance is equal to the Euclidean distance (De Maesschalck et al. 2000).

In the present analysis, the articulatory difference between the palatalised and plain consonant of each pair is the main point of interest: i.e. the distance between /r^j/ and /r/ and between /l^j/ and /l/. First, the centroid for each consonant, speaker, and experiment condition (word position, vocalic context, and speech rate) was calculated. A total number of 288 centroids was calculated (4 consonants * 6 speakers * 2 word positions * 3 vowels * 2 speech rates). Then, the Mahalanobis distance from each token from one consonant (e.g. /r/) to the centroid of the other consonant (e. g. /r^j/) and reverse was calculated.

Statistical analysis

The statistical analysis with a) Mahalanobis distance between the palatalised and the plain consonant or with b) the tongue dorsum position as dependent variable, speech rate (two levels: slow vs. fast), word position (two levels: non-final vs. final), and vowel (three

was taken in order to have a uniform analysis.

levels: /a/ vs. /i/ vs. /u/) as fixed factors and speaker (speakers V1-V6) as the random factor was performed with linear mixed models and post-hoc Tukey tests using package lmerTest in R.

2.4 Results

2.4.1 Articulatory distance between palatalised and plain consonants

First, the results of the Mahalanobis distance between the palatalised and the plain consonant of each pair, measured in the tongue dorsum position will be presented. Figure 2.3 shows the spatial distribution of tongue-dorsum positions in palatalised and plain rhotics and laterals in a normalised space for all speakers. It can be observed that the distance is smaller overall between palatalised and plain rhotics (black triangles) than between laterals (grey dots). Moreover, there is a tendency to a greater overlap between palatalised and plain rhotics in word-final than in initial/medial position in /a/- and /i/-contexts. The distance between palatalised and plain laterals also seems to be smaller in word-final than in initial/medial position in /i/- and /u/-contexts.

The statistical analysis with Mahalanobis distance as a dependent variable and liquid (/r^j/-/r/-distance vs. /l^j/-/l/-distance), word position (non-final vs. final), vowel (/a/ vs. /i/ vs. /u/), and speech rate (slow vs. fast) has shown a significant main effect of liquid. The averaged distance between palatalised and plain rhotics is 5.16 mm (standard deviation: 0.26 mm) and between palatalised and plain laterals 8.98 mm (standard deviation: 0.29 mm).[8]

In the following, the analysis of the influence of word position, speech rate, and vocalic context will be presented for each pair of liquids separately. Due to the complex design (the presence of four factors), it has been decided to split the data into two groups and to perform the statistical analysis for each pair separately.

Mahalanobis distance between palatalised and plain rhotics

First, consider the distribution of Mahalanobis distance between palatalised and plain rhotics in different contexts in Figure 2.5. The Mahalanobis distance between /r^j/ and /r/ seems to be smaller in /i/-context as compared to /a/-context.

The statistical analysis of Mahalanobis distance between palatalised and plain rhotics

[8] Calculated as Euclidean distance on real data.

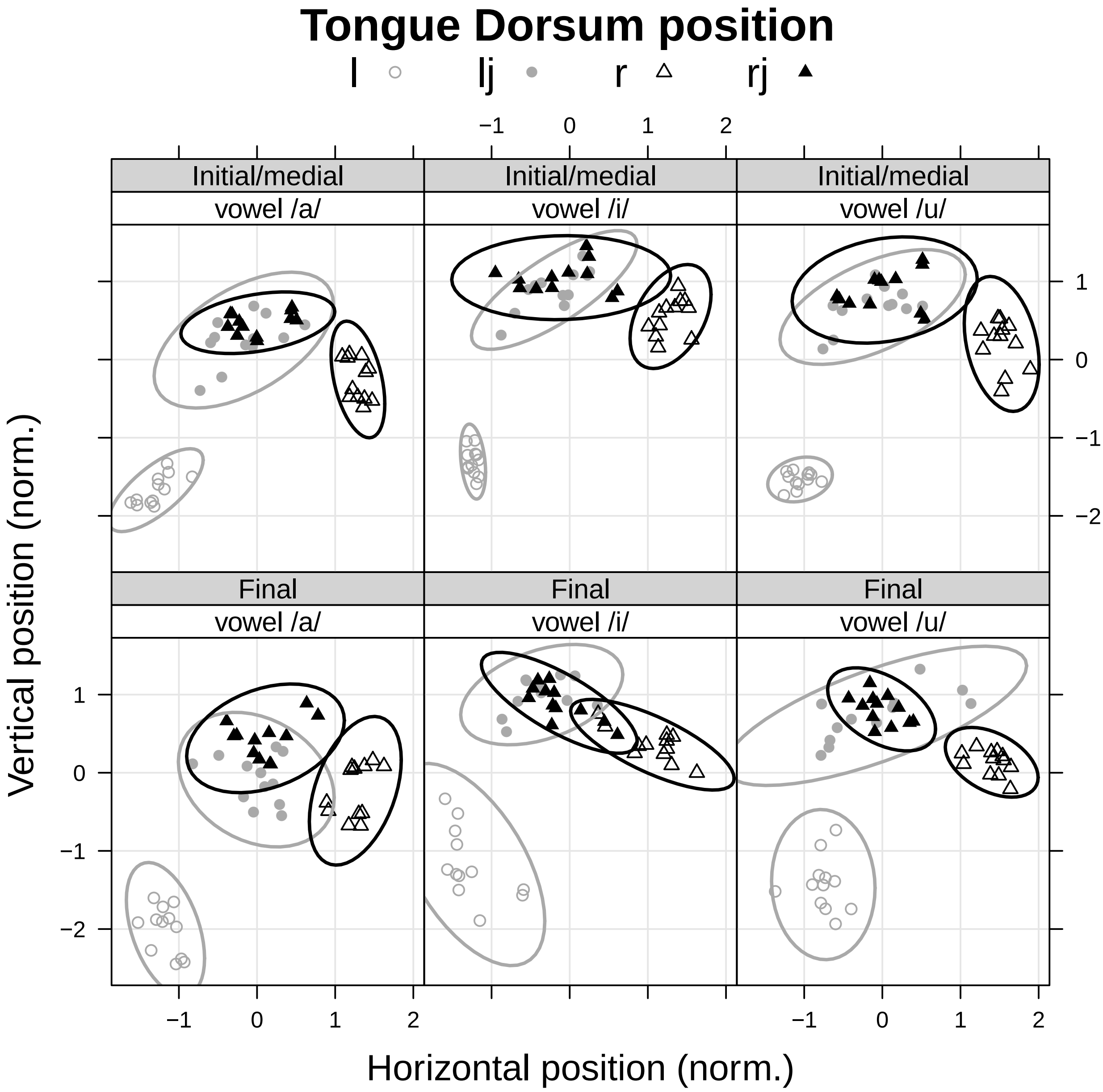


Figure 2.3: Normalised tongue dorsum positions of /l/, /l^j/ (empty and filled dots), /r/, and /r^j/ (empty and filled triangles) in initial/medial (top) and final (bottom) word positions, in /a/, /i/, and /u/ contexts. Lips are on the left.

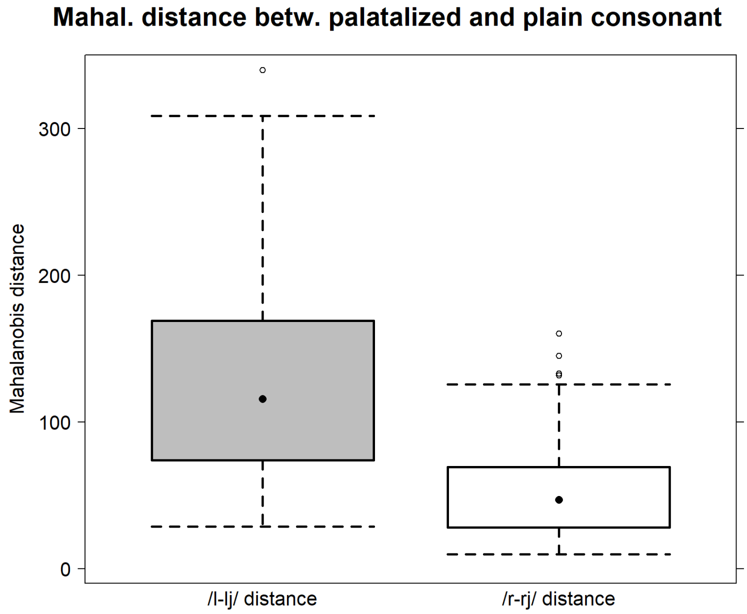


Figure 2.4: Mahalanobis distance between palatalised and plain consonant of each pair (/l^j/-/l/ and /r^j/-/r/).

with vowel (/a/, /i/, /u/), word position (non-final, final), and speech rate (slow, fast) as fixed factors and with the speaker as a random factor showed the main effect of vowel ($F[2] = 13$, $p < 0.001$), and two-way interactions between word position and vowel ($F[2] = 26$, $p < 0.001$), between vowel and speech rate ($F[2] = 23.8$, $p < 0.001$), and a small interaction between position and speech rate ($F[1] = 3.9$, $p < 0.05$).[9]

Post hoc Tukey tests showed no significant difference between non-final and final positions for /i/- and /a/-contexts ($p > 0.1$). The Mahalanobis distance was even greater in final position than in non-final position in /u/-context at both speech rates ($p < 0.05$). The Mahalanobis distance between /r^j/ and /r/ was smaller in the context of /i/-vowel in word-final position as compared to /u/ ($p < 0.001$) and to /a/ at slow speech rate ($p < 0.05$). In word-initial position, the Mahalanobis distance was smaller in /i/-context only in comparison to /u/ at a fast speech rate ($p < 0.01$). The speech rate had only a weak influence on the Mahalanobis distance between /r^j/ and /r/ in initial/medial position for /a/-context ($p = 0.067$).

[9] Six per cent of the outliers was removed at each side (twelve percent of the data).

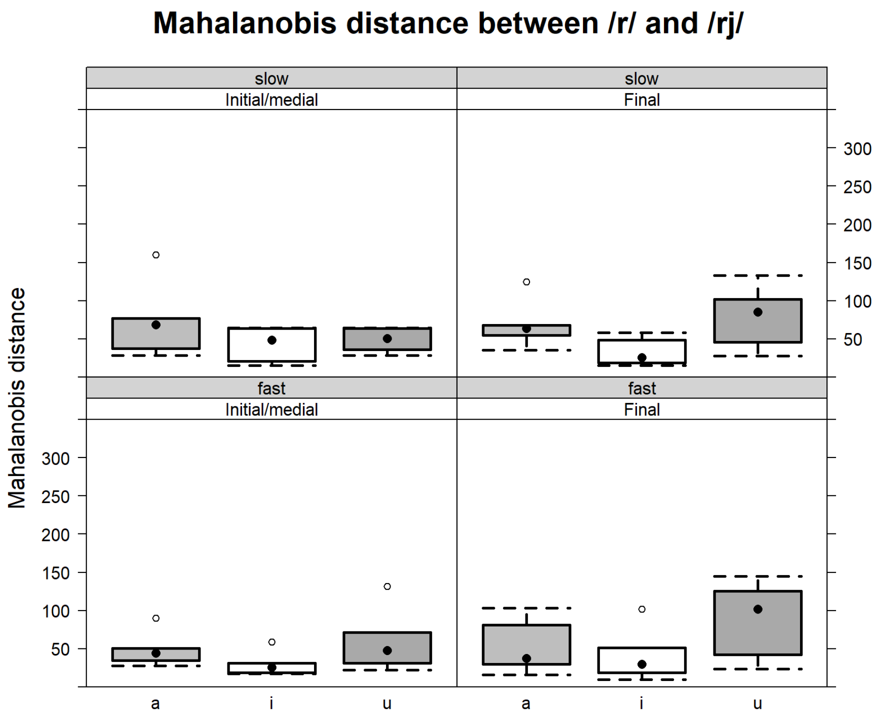


Figure 2.5: Mahalanobis distance between /r/ and /r^j/ in initial/medial (left) and final (right) word positions; at a slow (top) and a fast (bottom) speech rate; in different vocalic contexts: /a/, /i/, and /u/.

In sum, we see no significant influence of word position on the distance between palatalised and plain rhotics. Contrary to the predictions, the articulatory distance between tongue dorsum gestures in /r^j/ and /r/ is not smaller in word-final position as compared to word-initial/medial position. Although the data suggest that the distance between /r^j/ and /r/ is smaller in the context before high vowels in initial/medial position, no significant difference was observed in the statistical analysis. Speech rate also had very little influence only in /a/-context in word-initial/medial position. The distance between tongue dorsum positions between palatalised and plain rhotics seems to be quite stable.

Mahalanobis distance between palatalised and plain laterals

Figure 2.6 presents the Mahalanobis distance between palatalised and plain laterals in different contexts. As in the case of rhotics, the distance between laterals does not seem to be influenced by word position. For laterals, a separate mixed model with Mahalanobis distance as a dependent variable and with the same fixed factors was performed. Neither of the three factors showed the main effect. A two-way interaction between position and vowel ($F[2] = 56.6$, $p < 0.001$), vowel and speech rate ($F[2] = 19.1$, $p < 0.001$), and a three-way interaction between position, vowel, and speech rate ($F[2] = 12.3$, $p < 0.001$) was observed.

Indeed, the post hoc Tukey tests revealed a significant difference between initial/medial and final positions only in /a/-context at a faster speech rate ($p < 0.01$): the distance between /l^j/ and /l/ was even greater in word-final position.

Unlike rhotics, the distance between /l^j/ and /l/ seems to be smaller in the /a/-context as compared to /i/- and /u/-contexts, in initial/medial position. The distance between /l^j/ and /l/ was indeed significantly smaller in initial/medial position in /a/-context in comparison to /u/ (slow: $p < 0.001$, fast: $p < 0.01$) and /i/ (slow: $p < 0.05$, fast: $p < 0.01$). The Mahalanobis distance was greater in word-final position at a fast speech rate in /a/-context vs. /u/ ($p < 0.01$). The Mahalanobis distance was significantly greater at a faster speech rate (vs. slow) in /a/-context in word-final position ($p < 0.001$).

To summarise the results, it has been observed that the word position had very little influence on the Mahalanobis distance between the plain and the palatalised consonant of each pair (both rhotics and laterals). The vocalic context had more influence: although not always significantly different, however. Here, the most remarkable finding is that the distance between /l^j/ and /l/ is small in word-initial/medial position in /a/-context, as compared to other contexts.

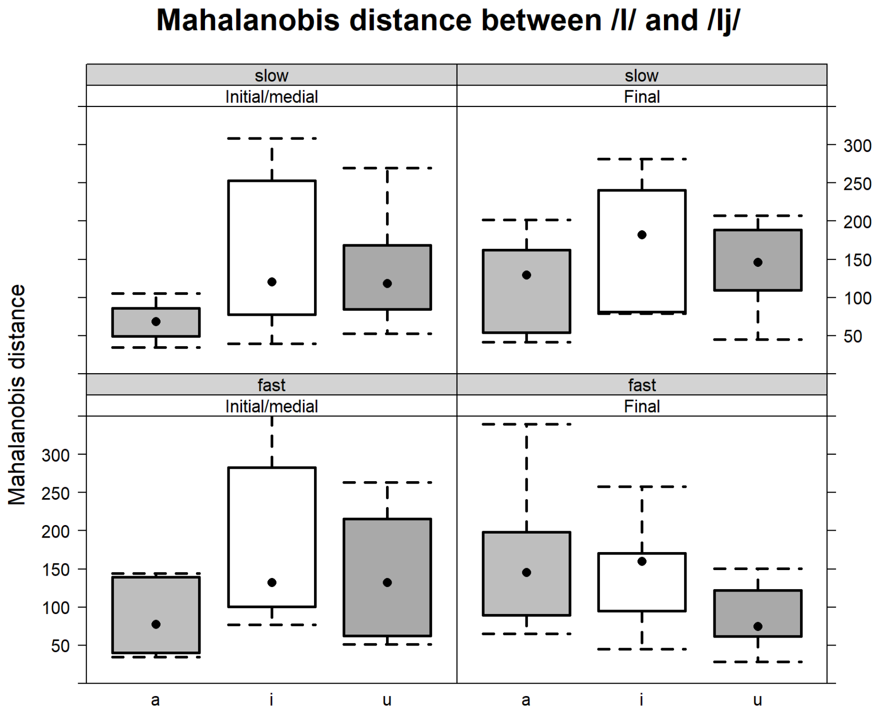


Figure 2.6: Mahalanobis distance between /l/ and /lʲ/ in initial/medial (left) and final (right) word positions; at a slow (top) and a fast (bottom) speech rate; in different vocalic contexts: /a/, /i/, and /u/.

2.4.2 Tongue dorsum position in palatalised rhotics and laterals

The second aim was to investigate how the secondary gesture in a palatalised consonant itself is influenced by word position, vocalic context, and speech rate. For this, the influence of these factors on the vertical and horizontal positions in tongue dorsum gesture in /r^j/ and /l^j/ was analysed.

Four separate statistical analyses with vertical and horizontal tongue dorsum position[10] in /r^j/ and /l^j/ as dependent variable and word position, vowel, and speech rate as fixed factors and speaker as the random factor were performed.

The statistical analysis showed the main effect of vowel ($F[2] = 48.3$, $p < 0.001$) and speech rate ($F[1] = 10.2$, $p < 0.05$), and two-way interactions between position and vowel ($F[2] = 9.1$, $p < 0.001$), and position and speech rate ($F[1] = 18.3$, $p < 0.001$) on the vertical position in /r^j/. The post hoc Tukey tests showed that the vertical tongue dorsum position in /r^j/ was similar in non final and final word positions, except in the context of /i/-vowel. In this context, the tongue dorsum was reduced in final position at fast speech rate, compared to non final position ($p < 0.001$). The vertical tongue dorsum position was influenced by the vocalic context: it was the highest in /i/-context, followed by /u/-context, and the lowest in /a/-context ($p < 0.01$, except for final position with similar tongue dorsum position for /u/- and /i/-contexts).

The statistical analysis with the horizontal tongue dorsum position in /r^j/ as fixed factor showed small main effect of speech rate ($F[1] = 6.8$, $p < 0.05$), and a two-way interaction between position and vowel ($F[2] = 4.7$, $p < 0.01$). However, the post hoc Tukey tests showed no significant effect of fixed factors.

The statistical analysis with the vertical tongue dorsum position in /l^j/ as fixed factor showed the main effect of vowel ($F[2] = 178.1$, $p < 0.001$), and two-way interactions between position and vowel ($F[2] = 57.4$, $p < 0.001$), position and speech rate ($F[1] = 13.1$, $p < 0.001$), and vowel and speech rate ($F[2] = 13.2$, $p < 0.001$). The post hoc Tukey tests revealed that the tongue dorsum was significantly reduced in word final position in /a/ context at both speech rates ($p < 0.001$), and in /i/-context at a slow speech rate ($p < 0.05$). Similar to /r^j/, the tongue dorsum was significantly influenced by the vocalic context with the highest tongue dorsum position in /i/-context, followed by /u/-, and with lowest position in /a/-context ($p < 0.01$, except non-final position /i/ vs. /u/: $p < 0.05$). Speech rate had influence on the vertical tongue dorsum in final position in /u/-context (p

[10] Similarly to the previous analysis, the tongue dorsum positions in the midpoint of the tongue tip plateau were investigated.

< 0.01).

The statistical analysis with the horizontal tongue dorsum position in /l^j/ as fixed factor showed small main effect of speech rate ($F[1] = 7.6$, $p < 0.05$), and a two-way interaction between position and vowel ($F[2] = 10.7$, $p < 0.01$). The post hoc Tukey tests showed small significant effects in word final position between /i/- and /a/-contexts ($p < 0.05$ at a slower speech rate; $p = 0.05$ at a faster speech rate). The factor speech rate had influence only in /a/-context in non final position ($p < 0.05$).

2.5 Discussion

The present study investigated the stability of articulatory difference between palatalised and plain liquids. Since the tongue dorsum raising is the primary articulatory manifestation of secondary palatalisation (Kochetov 2005), the tongue dorsum position in a two-dimensional space was chosen as the main point of investigation. First, the intention was to analyse whether the articulatory difference is greater between /l^j/ and /l/ than between /r^j/ and /r/, as reported earlier (Kochetov 2005). Second, the influence of several conditions like word position, vocalic context, or speech rate on the articulatory difference between palatalised and plain consonants of each pair was analysed. The main prediction was that since trilling and palatalisation impose antagonistic requirements on the tongue dorsum (Ladefoged and Maddieson 1996, Kavitskaya 1997), unfavourable conditions would lead to the reduction in the tongue dorsum in /r^j/ in order to resolve this conflict. Consequently, a reduced tongue dorsum gesture in /r^j/ and a greater overlap between the plain /r/ and following high vowel would lead to an even smaller distance between tongue dorsum positions /r^j/ and /r/ in word-final position and before /i/, unlike in the context of /a/-vowel. As a result, the acoustic difference between /r^j/ and /r/ would also be smaller (measured in F2 values, the main acoustic correlate of the secondary palatalisation), which in turn would lead to the perceptual confusability.

In order to compare the relative articulatory difference between palatalised and plain consonants, the Mahalanobis distance between the tongue dorsum positions was calculated. First, the results confirm the previous findings (Kochetov 2005) that the articulatory difference is significantly greater between laterals than between rhotics. Second, the articulatory difference in both pairs was not substantially influenced by unfavourable factors. Contrary to the prediction, the distance between /r^j/ and /r/ was similar in non-final and final word positions. Surprisingly, the difference between /r^j/ and /r/ was even greater in /u/-context in final, as compared to non-final position. Similarly, the difference between laterals was not influenced by word-position. In laterals, the distance was even greater in /a/-context in word-final position. The analysis of the vertical and horizontal tongue dorsum position in /r^j/ showed almost no spatial reduction word-finally. These results are consistent with the acoustic analysis conducted by Iskarous and Kavitskaya (2010), who found that the secondary gesture in palatalised rhotics was consistently high in all word positions.[11]

In laterals, however, the tongue dorsum was significantly reduced in some vocalic contexts in word-final position. This, and also the fact that the horizontal tongue dorsum position varied depending on the context in laterals but not in rhotics, suggests that the tongue dorsum is indeed highly constrained in rhotics, even in palatalised rhotics, and less so in laterals. Even palatalised rhotics present a highly constrained tongue dorsum. In sum, the analysis showed that the secondary gesture is relatively stable and is not reduced in /r^j/, compared to /l^j/.

2.5.1 Articulation-based explanations

Articulatory Phonology

In the framework of AP, gestural reduction and increased overlap have been claimed to be the main articulatory reasons for many sound changes (Browman and Goldstein 1991, Bybee 2015). These phenomena would be expected to be more pronounced at faster speech rates, which correspond to hypoarticulated speech (Browman and Goldstein 1991). It has been shown in several previous studies that consonants often present gestural reduction or reduction in magnitude or duration in coda as compared to onset position (see Krakow 1999). The main idea in the present study was thus to investigate in more detail whether the palatalisation gesture would be reduced in coda-consonants, compared to onset-consonants. Since the raised tongue dorsum is the primary correlate of palatalisation (Bondarko 2005, Kochetov 2005), the main hypothesis was that the gestural reduction of the secondary gesture will lead to an even smaller articulatory difference between palatalised and plain consonants in word-final position. As a result, the two consonants would be poorly distinguished from each other in this position, especially in the case of /r^j/-/r/, where the articulatory distance is already quite small. In addition, the high front vowel /i/ would greatly overlap with the preceding plain consonant, and in this way also reduce the articulatory distance in this position. A smaller articulatory difference between the palatalised

[11] See Scobbie et al. (2009) on similar stability of the tongue dorsum in onset vs. coda position for some speakers in Dutch.

and plain consonants will cause a confusing acoustic result. Hereby, the difference between rhotics would be even smaller than between laterals and thus more impaired.

The present analysis did not confirm the hypotheses: the Mahalanobis distance between /r^j/ and /r/ was not significantly influenced by word position, speech rate, or vocalic context. Contrary to the predictions, the distance between /l^j/ and /l/ seemed to be even greater in /i/- and /u/-contexts, compared to /a/. The analysis of the tongue dorsum position showed almost no gestural reduction in /r^j/. In sum, the AP-framework can't explain the contrast neutralisation between /r^j/ and /r/ in word-final position and before high front vowels.

The DAC-model

Recasens (2004) claims that some consonants should present little reduction even in word-final position because of the articulatory constraints imposed on them. He includes laterals into the group of consonants which would normally be reduced in word-final position. However, rhotics (trills) should not present syllable-final gestural reduction because they are very constrained sounds.

The present results are in line with the DAC-assumption that rhotics, in general, are very constrained sounds (Recasens 2013a); even palatalised rhotics are highly resistant to the influence of different factors. The tongue dorsum in /r^j/ was not reduced in word-final position, thus confirming this prediction. Although palatalised laterals present complex articulation, the tongue dorsum in /l^j/ is not as constrained as in the case of /r^j/ and thus can be slightly reduced word-finally. Contrary to the DAC-predictions, the distance between /r^j/ and /r/ was not significantly smaller in the context of /u/- and especially of /i/-vowels, compared to /a/. It remains to be investigated in the future whether these results are due to the fact that /r/ does indeed not overlap significantly with /i/ and /u/ or whether another, more appropriate analysis should be used instead. In sum, the DAC-model is also not able to explain why the opposition /r^j/-/r/ is neutralised more often in coda than in onset position and before /i/- than before /a/-vowel, for the pure articulatory reasons.

2.5.2 Perceptual explanation

The framework of Articulatory Phonology and the DAC-model do not provide a sufficient explanation for the positional contrast neutralisation between /r^j/ and /r/. It should then be tested whether the perception may play a crucial role in these sound changes. The contrast neutralisation in the context of high vowels may be due to hypercorrection. As Ohala (1994) explains in his paper on hierarchies of environments for secondary palatalisation, the listener knows that the consonant is normally slightly palatalised due to the coarticulation with the high front vowel. When the listener hears the phonologically palatalised consonant followed by /i/, he or she may attribute the high F2 values entirely to the vowel and interpret the consonant as plain. The listener, thus, would over-normalise. Ohala hypothesises that in a perception experiment, the discrimination between palatalised and plain consonants would produce more "plain"-responses in the context of high vowels, compared to low vowels. A piece of evidence for this comes from the study by Babel and Johnson (2010), who found out that both L2- and L1-Russian speakers differentiate the contrast between palatalised and plain Russian consonants less effectively in the context of /i/-, than of /a/-vowel. Still, a perceptual analysis is necessary in order to confirm this hypothesis.

Chapter 3

Intergestural organisation and CV-overlap in palatalised liquids

Summary

The present chapter investigates, first, the temporal organisation between primary and secondary gestures in palatalised liquids in distinct word positions and at different speech rates. Second, the overlap between the secondary gesture and the vowel /a/ in word-initial and -final positions is examined. The results show that there is a greater variation in intergestural timing in /r^j/ than in /l^j/, subject to domain position and speech rate. It is especially in word-initial position at a slow speech rate that the lag between two gestures in /r^j/ is the greatest. As a consequence, there is more overlap between the secondary gesture and the vowel in word-initial position for /r^j/ in comparison to /l^j/. Thus, the sequential and unstable timing and greater overlap between the palatalisation gesture and the following vowel in /r^j/ could be one of the possible causes for the sound change /r^j/ into /rj/ in Slovene, some dialects of Ukrainian, or Lower Sorbian.

3.1 Introduction

3.1.1 General information on glide insertion after palatalised consonants

Palatalised or palatal consonants often experience the change where a palatal glide is inserted before or after this consonant.[1] In Slavic languages, palatalised plosives changed into plain consonant plus palatal glide before low vowels in Czech and Ukrainian (Carlton 1991: 236, 283, Kochetov 2002: 23). Palatalised rhotics also changed into the sequence plain rhotic plus glide in Slovene or some dialects of Ukrainian (Greenberg 2000: 95-96, Carlton 1991: 311-312, Jakobson 2002: 216).

3.1.2 Mechanisms of glide insertion

The framework of Articulatory Phonology predicts that the segment insertion will occur due to the gestural overlap or the wrong timing between the involved gestures. For instance, Browman and Goldstein (1990b: 24) attribute the insertion of [p] in the example [sʌmpθɪŋ] for *something* to the wrong timing between the velic and the labial gestures in /m/ before an oral voiceless consonant, which would produce the perception of an inserted oral bilabial plosive, when the velum rises too early (adapting the explanation in Ohala 1974 and Anderson 1976). Likewise, Gick (1999: 51) explains the intrusion of [r] in words like [wɒrʃ] for *wash* as an overlap of the low vowel /a/, which has a pharyngeal component, with the tongue blade raising and the lip rounding inherent to /ʃ/. Applying this account to the glide insertion after a palatalised rhotic, it can be hypothesised that a delayed tongue dorsum raising gesture would be responsible for more prominent and lengthened F2 transitions, which could eventually be interpreted as a glide.

Although Ohala (1974) was one of the first researchers to suggest the articulation-based explanation for segment insertion, adapted later by Browman and Goldstein (1990b), he goes further in his argumentation and stresses the listener's role in sound change, in general, and in this particular case. For Ohala, the articulatory imperfection of the sort described above is ubiquitous, but the listeners are aware of this and compensate for it correctly. In some cases, however, the listeners may erroneously interpret the resulting acoustic outcome as a separate sound; in the present case, the prominent vocalic F2 transitions as a palatal

[1] A shortened version of this chapter has been published in the Proceedings of International Congress of Phonetic Sciences 2015, see Stoll et al. (2015).

glide /j/. For Ohala, this would be a case of hypocorrection, or failure to correctly rule out the acoustic imperfection due to the coarticulation between a palatalised consonant and the following low vowel (in line with the argumentation in Ohala 1993).

Recasens (2014: 28) agrees with Ohala' view that "a good number of glide insertions in VC and CV sequences appear to result from the phonemic categorization of the acoustic formant transitions" as a result of coarticulation between the consonant and the vowel. But Recasens also emphasises the significance of intergestural timing in complex sounds like palatalised consonants in Russian. Recasens (2014: 29) states that the glide insertion is more likely to take place in contexts with prominent vocalic transitions (especially when the timing between the consonant gestures is less synchronous), e.g. in the sequences with palatal or palatalised consonants flanked by low vowels. In this case, a quick change from high to low F2 values could potentially be interpreted as palatal glide by the listener. Recasens and Espinosa (2010) showed in a perception experiment that not only the prominent and lengthened F2 transitions but also higher F2 values of the vocalic transitions could be responsible for the eventual identification of vocalic transitions as a separate glide. Another piece of evidence for the importance of F2 values comes from Recasens' (2014: 40-41) observation that palatal lateral approximants /ʎ/ are less prone to posterior glide insertion than (alveolo)palatal /ɲ/ or /c/ because of lower F2 values in the former as compared to the latter.

In the DAC-model, the palatalised consonant and the low vowel differentiate in the degree of articulatory constraint of the tongue dorsum: The tongue dorsum is relatively unconstrained in /a/ but is supposed to be moderately or highly constrained in a palatalised consonant. Consequently, the tongue dorsum raising gesture (palatalisation) may easily overlap with the low vowel if necessary. Such a need could arise in a case when the timing between the primary and secondary gestures is sequential, as happens with palatalised rhotics (Kochetov 2005). A considerable overlap between delayed tongue dorsum raising and the following low vowel in a palatalised rhotic would lead to the lengthening of the vocalic transitions and to the perception of an i-offglide at the offset of the consonant.

In sum, from the articulatory point of view, the AP framework and the DAC-model would argue that the sequential timing between the primary and secondary gestures should be one of the key factors in the change from /r^{j}a/ into /rja/. The AP framework would predict that the overlap between tongue dorsum and the following vowel should increase even more at a fast speech rate (which in this study corresponds to hypoarticulated speech), while the DAC-model predicts that the less synchronous timing between the two gestures would cause more prominent F2 transitions with higher range values.

3.1.3 Intergestural timing

It has been observed that, cross-linguistically, liquids are often subject to sound change: they are prone to elision, metathesis, assimilation, dissimilation, etc. (Proctor 2009: 27-36, Müller 2011: 127-136). As far as their articulation is concerned, liquids have been hypothesised to consist of two gestures - consonantal tongue tip and vocalic tongue body gestures (Sproat and Fujimura 1993, Coleman 1992) - which are likely to overlap with neighbouring sounds. Thus, studying the articulatory organisation of liquids could shed more light on the sound change processes these consonants are involved in.

The temporal organisation between gestures in liquids has been subject to investigation in the past (Browman and Goldstein 1995, Gick et al. 2006, Kochetov 2005, Kochetov 2006a, Krakow 1999, Sproat and Fujimura 1993; see an overview in Müller 2011). Sproat and Fujimura (1993) suggested that the observed allophony between onset and coda lateral approximants in English may be due to the different timing between the tongue tip and the tongue dorsum. The authors claim that the nearly synchronous timing (or with slightly delayed tongue dorsum) between the two gestures in word-initial position produces the laterals with more "clear" nature, while the anticipated tongue dorsum gesture in word-final position gives rise to the perception of a more "dark" variant of the lateral. However, Gick et al. (2006), in a cross-linguistic study on liquids, found no straightforward correlation between intergestural timing and brightness/darkness of liquids. For instance, the authors observed that Serbo-Croatian "dark" /l/ presented simultaneous timing between the tongue tip and the tongue dorsum in all word positions. Gick et al. (2006) hypothesised that this effect is due to the fact that Serbo-Croatian has a phonological opposition between palatalised and plain laterals and thus presents a different pattern. This finding led the authors to stress the significance of other factors in the intergestural organisation, like phonology along with perceptual recoverability (see references in Chitoran et al. 2002), something which neither the AP nor Sproat and Fujimura take into consideration.

Other studies have investigated intergestural organisation in palatalised consonants more extensively (Kochetov 2005, 2006a, Recasens and Romero 1997, Zsiga 2000?). Although secondary palatalisation is described as a synchronous realisation of the primary and secondary gestures (Pompino-Marschall 2003: 316), previous studies have shown that this is not always the case. The findings on intergestural organisation in palatalised consonants in different word positions are ambiguous. One possible explanation for this is that the timing may vary depending on the consonant involved. For instance, while Recasens and Romero (1997) found out that Russian palatalised alveolar nasals /n^j/ have sequential timing with delayed tongue dorsum, Kochetov (2006a) found that the timing in /p^j/ varies depending on word position. Kochetov (2006a) analysed Russian palatalised and plain labial plosives and the palatal glide /j/ in different word positions and discovered that the tongue dorsum is delayed in onset /p^j/, but precedes the tongue tip in coda position. These results are in line with the hypothesis suggested by Sproat and Fujimura (1993) that the more vocalic (dorsum) gesture should occur close to the syllable nucleus, while the more consonantal (tongue tip) gesture tends towards the syllabic periphery. Kochetov also noticed that the intergestural timing in /p^j/ was more variable in coda than in onset position, which is in line with AP-predictions about looser connection in VC than in CV sequences. Findings in Zsiga (2000) also suggest indirectly that Russian palatalised postalveolar fricatives have relatively synchronous and stable timing, at least compared to English fricatives.

In another study, Kochetov (2005) analysed Russian palatalised and plain liquids in coda position and showed that the timing between primary and secondary gestures is nearly simultaneous in laterals but sequential in rhotics, where the tongue body raising gesture is delayed with respect to the tongue tip. This finding contradicts the Sproat and Fujimura hypothesis, since both /l^j/ and /r^j/ deviate in their production from the predicted pattern on timing. At the same time, the AP framework is not able to explain why Russian coda /p^j/, /l^j/, and /r^j/ differ in timing (presenting advanced tongue dorsum, simultaneous timing and delayed tongue dorsum, respectively). While the simultaneous timing in palatalised laterals could be due to the tighter connection between the two gestures due to the phonemic quality of palatalisation (Gick et al. 2006), the delayed tongue dorsum gesture in /r^j/ may be due to the articulatory incompatibility between the two gestures (Ladefoged and Maddieson 1996, Kavitskaya 1997). The aim of the present study is thus to investigate intergestural timing in palatalised /r^j/ and /l^j/ in more detail by expanding the analysis to other word positions and different speech rates.

3.1.4 CV-overlap

The intergestural coordination of consonants has important implications for syllabic structure. In the framework of Articulatory Phonology, the consonant and the vowel are tightly connected syllable-initially: they start nearly simultaneously (present in-phase coupling) and thus greatly overlap. In contrast, the word-final VC sequence is supposed to be organised sequentially, or in anti-phase, where the articulation of the coda consonant begins when the vocalic articulation is ceasing (Browman and Goldstein 1988, 1995, 2000, Marin and Pouplier 2010). As a consequence, the connection between the vowel and the coda consonant is looser, presents more variation and less overlap (Browman and Goldstein 1990b). Browman and Goldstein (2000) expand this idea to consonant clusters and state that two consonants in word-initial position should be organised synchronously with the following vowel but in anti-phase with respect to each other. Coda clusters are coordinated anti-phase with respect to the preceding vowel and between each other. Here again, the onset clusters should overlap more with the following vowel than the offset clusters with the preceding vowel (see Honorof and Browman 1995, Pouplier 2012, Marin 2013, Marin and Pouplier 2010 for empirical evidence).

However, it is not clear how consonants with complex articulation are organised at syllabic level. Will there be more overlap between the tongue dorsum and the vowel in the sequence /r^ja-/ in word-initial position as compared to the word-final position or to the sequence /l^ja-/, as predicted by Articulatory Phonology? Or is the relation between the two gestures sequential as in a cluster, so the following vowel is not affected by the delayed tongue dorsum gesture in /r^j/?

In the case when primary and secondary gestures in a consonant are organised simultaneously, which is predicted for onset and coda /l^j/, both gestures are expected to present in-phase coupling with respect to each other in all positions, and with the following vowel. Consequently, more overlap between the secondary gesture and the following vowel in onset than in coda is expected in palatalised laterals, and both gestures are anti-phased with the preceding vowel in VC sequence. In contrast, the sequential timing between the two gestures in /r^j/ would lead to a greater overlap between the secondary gesture and the vowel than in /l^j/, in onset. In coda position, the overlap will be smaller between the vowel and the tongue dorsum in coda-/r^j/, compared to coda-/l^j/.

The second aim of the present study is, then, to analyse the intergestural coordination between palatalised consonants and the vowel /a/. Since /r^j/ presents sequential timing between primary and secondary gestures (Kochetov 2005), more overlap between the secondary gesture and vowel in initial position for /r^j/ than for /l^j/ is expected. Inversely, there should be less overlap between the secondary gesture and the preceding vowel in word-final position in /r^j/, unlike /l^j/.

3.2 Hypotheses

The following hypotheses will be investigated here:

H1: The timing between the two gestures is simultaneous in /$\mathrm{l^j}$/, but sequential in /$\mathrm{r^j}$/ in all word positions because of the articulatory incompatibility between trilling and palatalisation and according to the previous studies (Kochetov 2005, Gick et al. 2006, Iskarous and Kavitskaya 2010).

H2: The articulatory incompatibility is also responsible for less stable intergestural organisation in /$\mathrm{r^j}$/ than in /$\mathrm{l^j}$/. Thus, more variable timing is expected in the former than in the latter due to the influence of speech rate or word position.

H3: Since the timing is expected to be sequential in /$\mathrm{r^j}$/ but not in /$\mathrm{l^j}$/, the secondary gesture and the following vowel overlap more in sequence /$\mathrm{r^j}$a-/, unlike /$\mathrm{l^j}$a-/. Hence, the sequence /$\mathrm{r^j}$a-/ presents transitions with higher F2 values than in the case of /$\mathrm{l^j}$a-/.

3.3 Method

3.3.1 Speech material

The data used in the present analysis are part of the articulatory experiment described in Chapter 2. Here, only palatalised consonants /$\mathrm{r^j}$/ and /$\mathrm{l^j}$/ flanked by low vowels /a/ will be investigated. Although it would be very interesting to explore the relation between palatalised liquids and high vowels as well as the intergestural organisation in plain /r/ and /l/ in Russian, such an analysis is beyond the scope of the present study and requires different data labelling. Since the labelling was based on maximum constriction positions (the script identified the target as maximum constriction position), only the clear tongue raising and falling gestures could be identified reliably. Thus, in the cases when the raised tongue dorsum gesture of the palatalised liquid was preceded or followed by a high vowel, a clear separation between the sounds was not possible. In the case of plain /r/ and /l/, the tongue dorsum often presented a clear steady state. But while the tongue dorsum slightly rises in /r/, it usually descends in /l/ by achieving its low target position even when preceded and followed by low vowels /a/. Thus, a different labelling should be applied in the future in order to properly identify the tongue dorsum target in /l/ and to be able to analyse the timing between the tongue tip and tongue dorsum in plain liquids.

The temporal organisation between primary and secondary gestures in /$\mathrm{r^j}$/ and /$\mathrm{l^j}$/ will be analysed in three word positions (initial, medial, final). The interplay between the palatalisation gesture and the flanking vowel will be investigated only in initial and final word positions because of the presence of bilabial consonants used as anchors in those word domains. The influence of speech rate (slow vs. fast) on timing will also be explored.

3.3.2 Measurements

Plateau duration

First, the temporal duration of tongue tip and tongue dorsum plateaus in /r^j/ and /l^j/, depending on word position and speech rate will be analysed:[2]

- $\text{Lag}_{[\text{TT-dur}]}$ (ms) = TT-plateau offset − TT-plateau onset
- $\text{Lag}_{[\text{TD-dur}]}$ (ms) = TD-plateau offset − TD-plateau onset

Relative timing between the primary and secondary gestures

In order to compare the relative timing between the primary and secondary gestures, the distance (lag) between the tongue tip and tongue dorsum plateaus will be investigated:

- $\text{Lag}_{[\text{onset}]}$ (ms) = TD-plateau onset − TT-plateau onset
- $\text{Lag}_{[\text{offset}]}$ (ms) = TD-plateau offset − TT-plateau offset
- $\text{Lag}_{[\text{midpoint}]}$ (ms) = TD-plateau midpoint − TT-plateau midpoint

In this case, lag values near to zero denote simultaneous timing between TT and TD, while positive lag values mean that the tongue dorsum is delayed with respect to the tongue tip.

In general, the results of the differences between plateau midpoints mimic the data of plateau onsets. But the former measurement seems to be more stable because it takes into account both onset and offset and analyses the relative position of the two gestures with respect to each other. However, it is known that the tongue tip can be faster and is able to achieve its target earlier due to to its smaller mass, as compared to the tongue dorsum (Hamann 2003: 33). It is also important to measure the difference in plateau offsets in order to analyse whether and how much the tongue dorsum is delayed (or not) with respect to the tongue tip.

[2] The detailed description of the data analysis and labelling is provided in Chapter 2.

Overlap between the palatalisation gesture and the vowel

It has been shown in previous studies (Kochetov 2005, Iskarous and Kavitskaya 2010) and is expected in the present analysis that palatalised rhotics would present delayed TD, unlike palatalised laterals, at least in some positions. It would be thus interesting to investigate how the tongue dorsum in /r^j/ and /l^j/ is coordinated with respect to the flanking vowels.

To analyse the CV-overlap, the interval between temporal TD-plateau midpoint and an anchor was measured. Lower lip maximum velocity of the following (or preceding, for the word-final position) labial consonant was selected as the anchor point. The lower lip maximum velocity onset was taken for word-initial position, and the offset for word-final position. Word-medial position was not considered here because the following consonant was an alveolar plosive. Figures 3.1 and 3.2 show the interval measurements between the temporal TD-plateau midpoint and lower lip maximum velocity onset.

Acoustic analysis

The acoustic segmentation was performed manually by means of Mtnew.[3] The acoustic durations were extracted from Mtnew and transferred to R (R Development Core Team 2008). The data were also transferred to EmuR (Winkelmann et al. 2016), where the formant values were automatically extracted and calculated. The formant values were also normalised by means of the Lobanov technique to be able to compare across speakers and different vocalic durations (see Harrington 2010: 186-187). Twenty percent of the F2 values from the consonant offset into the following vowel (for word-initial consonants) or from consonant onset into the preceding midpoint (for word-final consonants) have been automatically extracted by means of EmuR and analysed in R. For each token and each condition, a mean of the F2 values was calculated.

Statistical analysis

The statistical analysis with liquid (two levels: lateral vs. rhotic), speech rate (two levels: slow vs. fast) and word position (three or two levels: initial vs. medial vs. final or initial vs. final) as fixed factors and speaker (speakers V1-V6) as the random factor was performed with linear mixed models and post-hoc Tukey tests using package lmerTest in R.

[3] Mtnew (Multichannel signal display): http://www.phonetik.uni-muenchen.de/~hoole/articmanual

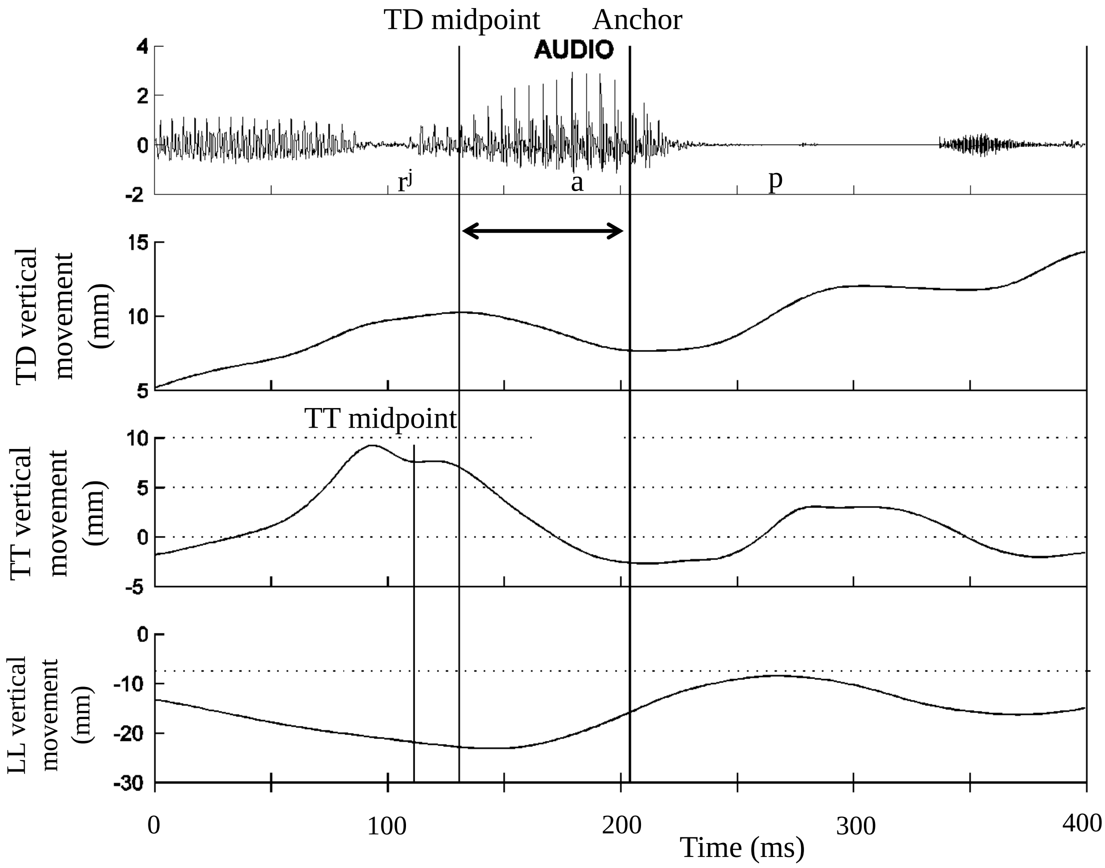


Figure 3.1: Example of articulatory measurements for /r^j/ in word-initial position at a slow speech rate (female Speaker V2).

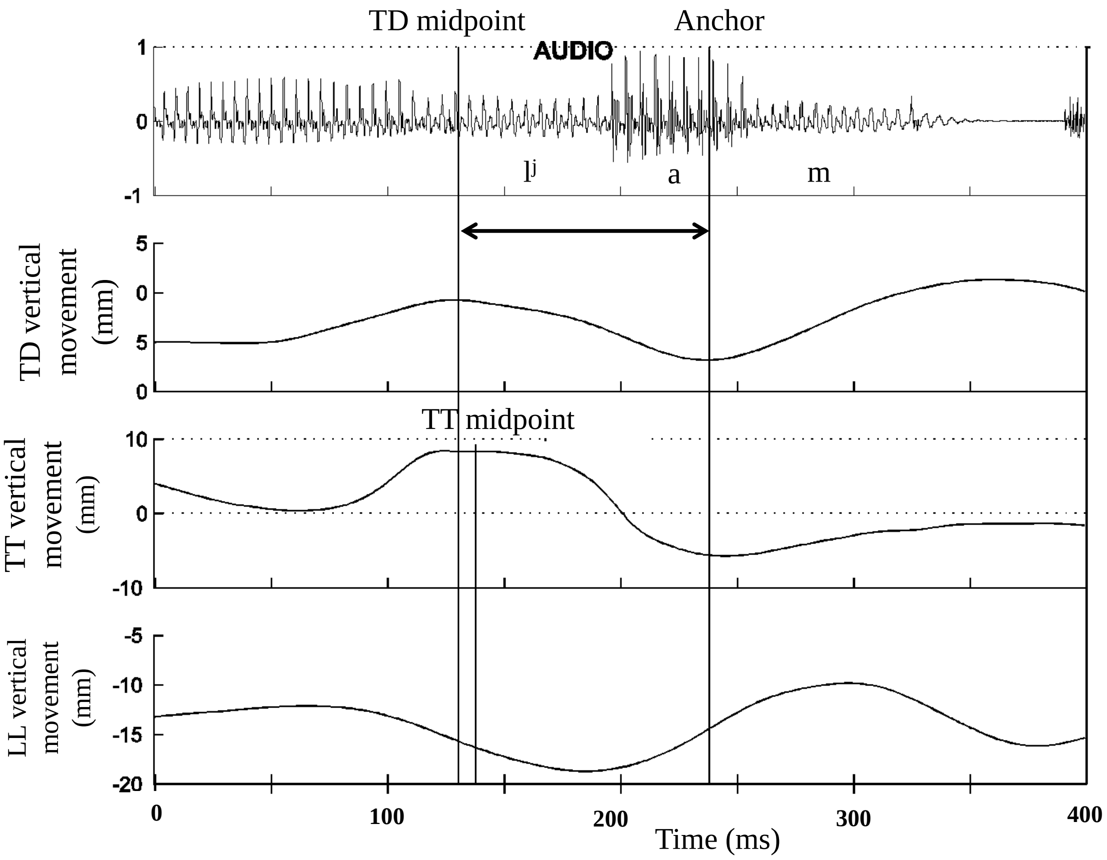


Figure 3.2: Example of articulatory measurements for /lʲ/ in word-initial position at a slow speech rate (female Speaker V2).

3.4 Results

3.4.1 Acoustic duration

The acoustic duration of palatalised liquids /l^j/ and /r^j/ is presented in Figure 3.3. It can be observed that palatalised laterals have longer durations than palatalised rhotics: (mean values: /l^j/: 65 ms, /r^j/: 38 ms). The statistical analysis with acoustic duration as a dependent variable and liquid (/l^j/ vs. /r^j/), position (initial vs. medial vs. final), and speech rate (slow vs. fast) as independent factors and with Speaker as the random factor revealed the main effect of liquid ($F[1] = 79.6$, $p < 0.001$), position $F[2] = 10.5$, $p < 0.05$), and speech rate ($F[1] = 47.7$, $p < 0.001$). There ware two-way interactions between liquid and position ($F[2] = 36.2$, $p < 0.001$), liquid and speech rate ($F[1] = 6.4$, $p < 0.05$), and a three-way interraction between liquid, position, and speech rate ($F[2] = 4.8$, $p < 0.01$).

Post-hoc Tukey tests showed that the acoustic duration of /l^j/ was significantly greater than that of /r^j/ overall ($p < 0.001$). The factor word position had no influence on the acoustic duration of /r^j/ ($p > 0.1$). The acoustic duration of /l^j/ was significantly smaller in final than in initial position at both speech rates ($p < 0.001$); it was smaller in medial than initial position at fast speech rate ($p < 0.001$), and it was smaller in final than medial position at slow speech rate ($p < 0.001$). The factor speech rate had a significant influence on the acoustic duration almost overall (at least, $p < 0.05$, except for /r^j/ in medial position: $p > 0.05$).

3.4.2 Timing

Plateau duration

The results of TT- and TD-plateau durations for /l^j/ and /r^j/ are shown in Figures 3.4 and 3.5. The TT-plateau seems to be greater in palatalised laterals than in palatalised rhotics (mean durations: 36 ms and 23 ms, respectively). The statistical analysis with TT-plateau duration as a dependent variable and liquid (/l^j/ vs. /r^j/), position (initial vs. medial vs. final), and speech rate (slow vs. fast) as independent factors revealed the main effect of liquid ($F[1] = 13.5$, $p < 0.05$), speech rate ($F[1] = 31.7$, $p < 0.01$), and two-way interactions between position and liquid ($F[1] = 12.3$, $p < 0.001$) and liquid and speech rate ($F[1] = 12.3$, $p < 0.001$). The TT-plateau duration is significantly greater in /l^j/ than in /r^j/ in initial position at slow and fast speech rates and in medial position at a slow speech rate ($p < 0.001$). The factor word position presented a small influence only

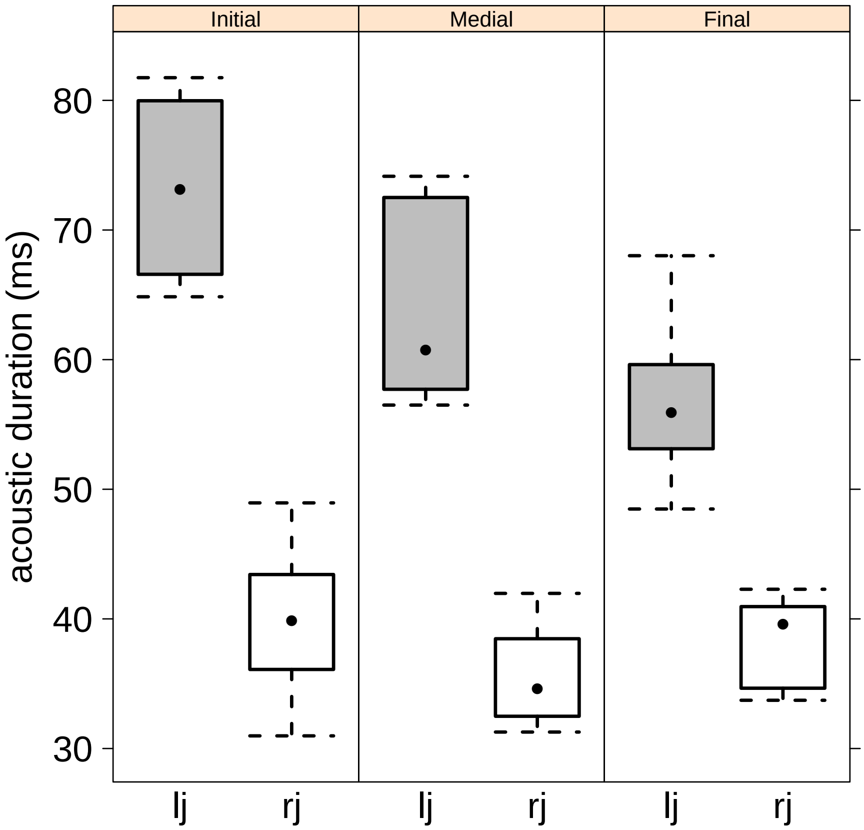


Figure 3.3: Acoustic duration (ms) in palatalised laterals /l^j/ and palatalised rhotics /r^j/ in initial, medial, and final word positions.

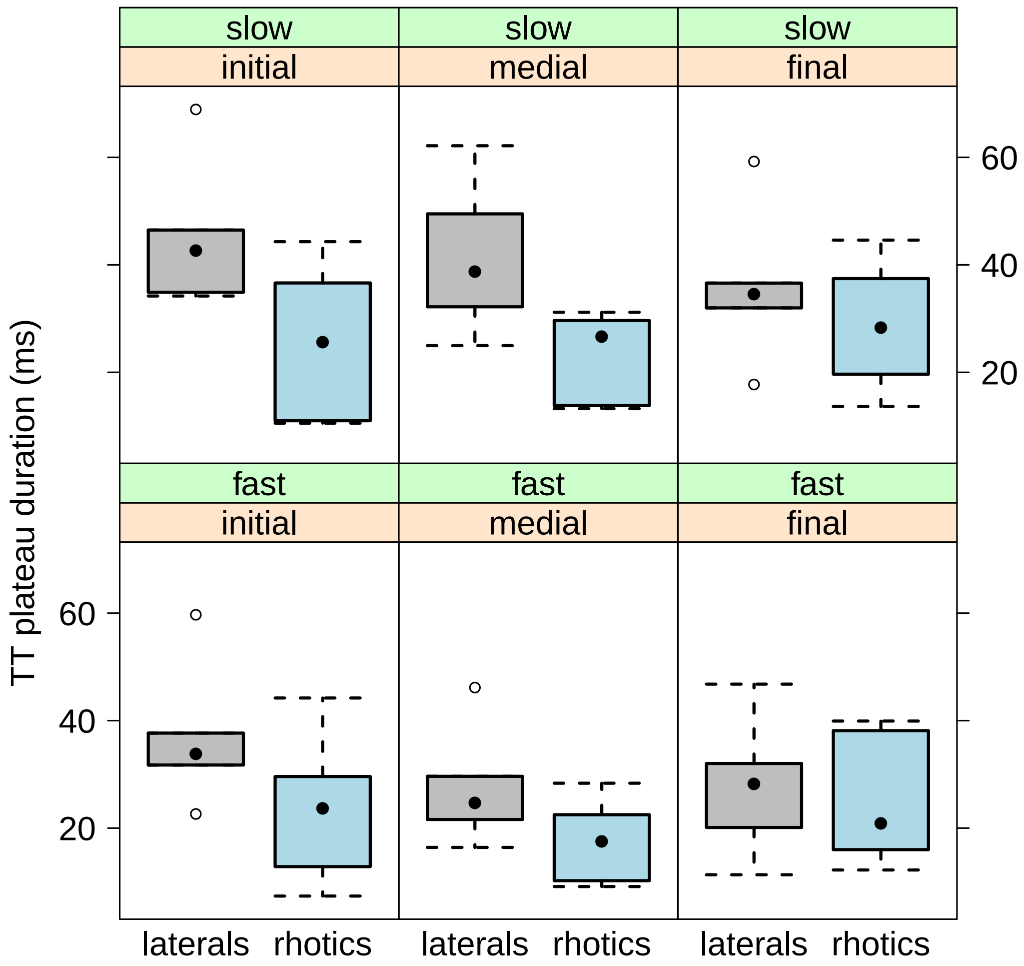


Figure 3.4: Tongue tip plateau duration (ms) in palatalised laterals /lʲ/ and palatalised rhotics /rʲ/ at a slow (top) and a fast (bottom) speech rate, in initial, medial, and final word positions.

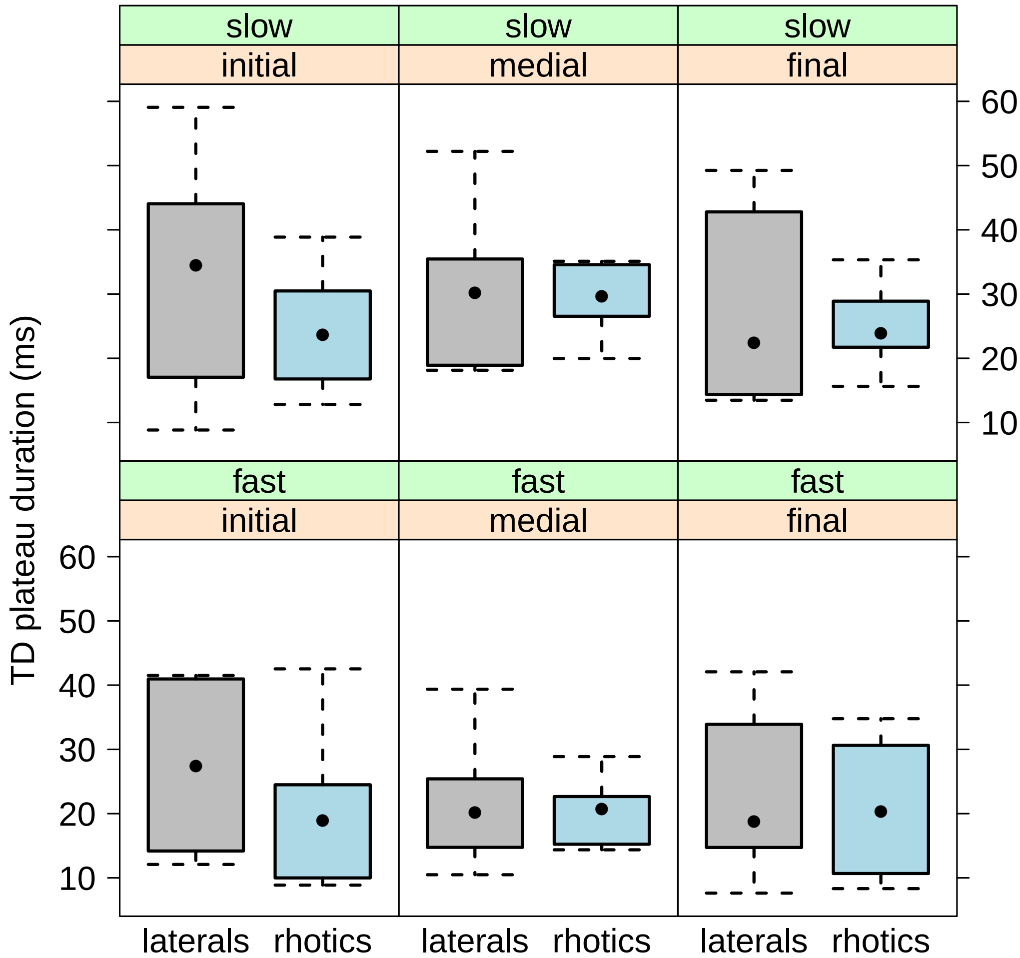


Figure 3.5: Tongue dorsum plateau duration (ms) in palatalised laterals /l^j/ and palatalised rhotics /r^j/ at a slow (top) and a fast (bottom) speech rate, in initial, medial, and final word positions.

on palatalised laterals at a fast speech rate (initial vs. medial: $p = 0.057$). The speech rate affected the TT-plateau duration only in /l^j/, with longer plateaus at a slower speech rate in all word positions ($p < 0.05$).

The liquids /l^j/ and /r^j/ have similar TD-plateau durations (mean values: 26 ms and 23 ms, respectively). In fact, the statistical analysis with TD-plateau duration as a dependent variable and the same fixed factors as in the previous analysis revealed no difference between palatalised laterals and rhotics ($p > 0.1$). The factor speech rate had a main effect on the TD-plateau durations ($F[1] = 10.7$, $p < 0.05$). An interaction between position and liquid ($F[1] = 4.8$, $p < 0.01$) has also been observed. The post-hoc Tukey tests showed that the TD-plateau duration was greater in /l^j/ and marginally in /r^j/ at slower than at faster speech rates only in medial word position ($p < 0.05$ and $p = 0.066$, respectively).

While the TT-duration is similarly short in palatalised rhotics in all conditions, it is subject to variation in palatalised laterals due to the influence of speech rate and marginally of word position. The relative stability of the TT-plateau duration in /r^j/ is probably due to the fact that palatalised rhotics are almost always realised as taps or approximants, i.e. almost never present more than one cycle (in line with the data from the acoustical study in Iskarous and Kavitskaya 2010). The liquids /r^j/ and /l^j/ have similar TD-plateau durations with little variation. However, the TD-plateau in both consonants is influenced by the speech rate in medial word position, where it seems to be less stable than in initial and final word positions.

Intergestural timing

Lag between plateau onsets

Figures 3.6 and 3.7 present the lag between the TD- and TT-plateau onsets for /r^j/ and /l^j/ in different word positions at fast and slow speech rates (mean values /l^j/: 6 ms and /r^j/: 13 ms). Recall that positive lag values mean that the palatalisation gesture is delayed with respect to the tongue tip gesture.

The statistical analysis with $lag_{[onset]}$ as a dependent variable and with liquid (rhotic vs. lateral), word position (initial vs. medial vs. final), and speech rate (slow vs. fast) as independent factors revealed the main effect of liquid ($F[1] = 8$, $p < 0.05$) and a small main effect of speech rate ($F[1] = 6.6$, $p = 0.053$), a two-way interaction between liquid and position ($F[2] = 66.4$, $p < 0.001$) and a three-way interaction between liquid, position, and speech rate ($F[2] = 4.3$, $p < 0.05$).

Both /r^j/ and /l^j/ present positive $lag_{[onset]}$ values meaning that the TT-plateau is achieved earlier than TD-plateau. The post-hoc Tukey tests showed that the $lag_{[onset]}$ was significantly different between rhotics and laterals in initial and final word positions ($p < 0.001$; initial fast: $p < 0.05$), but not in medial word position ($p > 0.1$). The $lag_{[onset]}$ was significantly influenced by the factors word position and speech rate in palatalised rhotics but not in laterals. In palatalised rhotics, the $lag_{[onset]}$ is greater in initial as compared to medial word position (slow: $p < 0.001$, fast: $p < 0.05$). The tongue dorsum is also more delayed in word-final position at a fast speech rate, as compared to medial position ($p < 0.05$). The speech rate affected the $lag_{[onset]}$ in /r^j/ in word-initial position: the tongue dorsum is more delayed at slow than at fast speech rates ($p < 0.01$). No significant influence of fixed factors on $lag_{[onset]}$ was observed in /l^j/.

Lag between plateau offsets

The difference between TD- and TT-plateau offsets can be observed in Figures 3.8 and 3.9 (mean values /l^j/: -4 ms, /r^j/: 13 ms). The statistical analysis with $lag_{[offset]}$ as a dependent variable and the same fixed factors showed the main effect of liquid ($F[1] = 12.7$, $p < 0.05$) and two-way interactions between liquid and position ($F[2] = 8.1$, $p < 0.001$), and liquid and speech rate ($F[1] = 10.9$, $p < 0.01$). Post-hoc Tukey tests revealed that the difference between /r^j/ and /l^j/ was significant in initial (slow: $p < 0.001$, fast: $p < 0.05$) and final word positions (slow: $p < 0.05$, fast = 0.057), only marginally significant in medial position at a slow speech rate ($p = 0.07$), but not at a fast speech rate ($p > 0.1$). The factors word position and speech rate had no effect on the $lag_{[offset]}$ in /r^j/, nor in /l^j/. The results show that the TD-plateau in /r^j/ is released later with respect to the TT-plateau. In /l^j/, however, the TD-plateau is released earlier, which is due to longer TT- than TD-plateau in /l^j/.

Lag between plateau midpoints

The $lag_{[midpoint]}$ presents a pattern similar to the cases of $lag_{[onset]}$ and $lag_{[offset]}$ (mean values /l^j/: 1 ms, /r^j/: 13 ms), but is supposed to present more normalised data. The statistical analysis with the $lag_{[midpoint]}$ as a dependent variable and with the same fixed factors showed a significant main effect of liquid ($F[1] = 18.9$, $p < 0.01$), a two-way interaction between liquid and position ($F[2] = 33.5$, $p < 0.001$), liquid and speech rate ($F[1] = 9.7$, $p < 0.01$), and a small three-way interaction between liquid, position, and speech rate ($F[2] = 3.6$, $p < 0.05$). The post-hoc Tukey tests revealed that the $lag_{[midpoint]}$ is significantly different between rhotics and laterals in word-initial and -final positions ($p < 0.01$), but not in word-medial position ($p > 0.1$). The factor speech rate has influence only on the $lag_{[midpoint]}$ in rhotics in word-initial position, where the TD-plateau is more

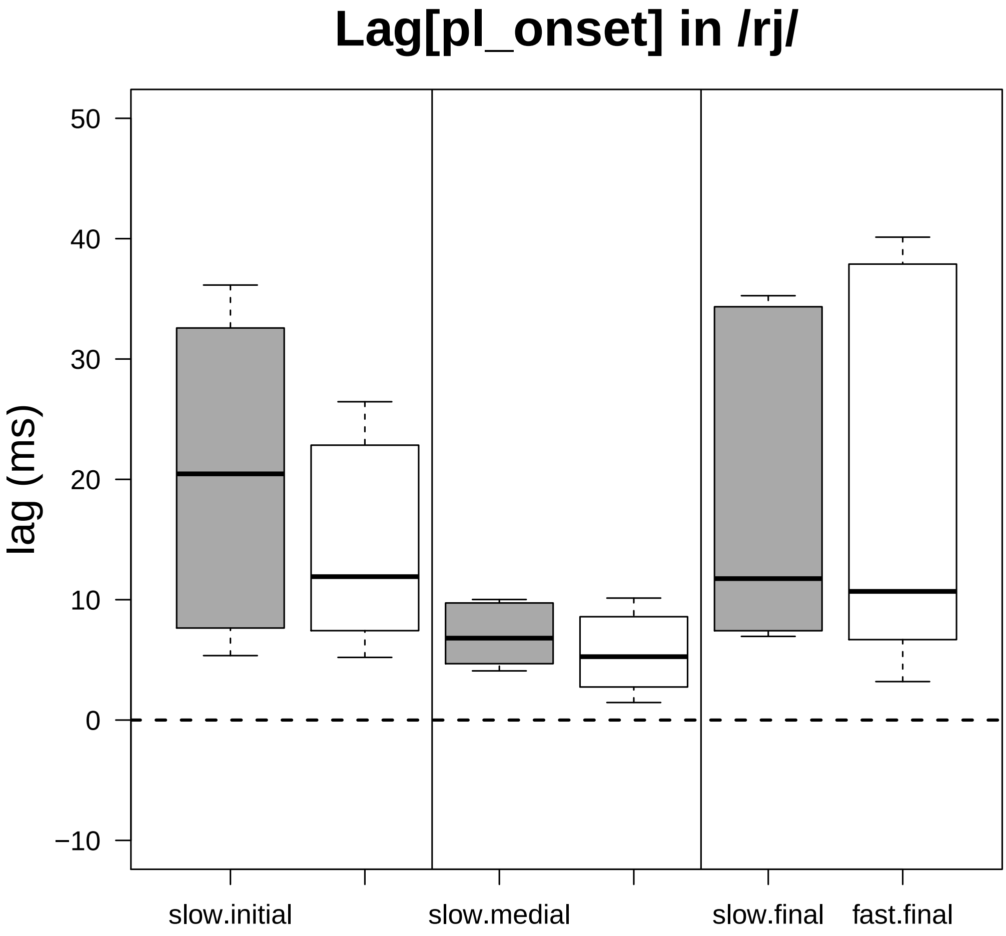


Figure 3.6: Lag between tongue dorsum and tongue tip plateau onsets in /r^j/ at slow (grey) and fast (white) speech rates, in word-initial (left), -medial (middle), and -final (right) positions.

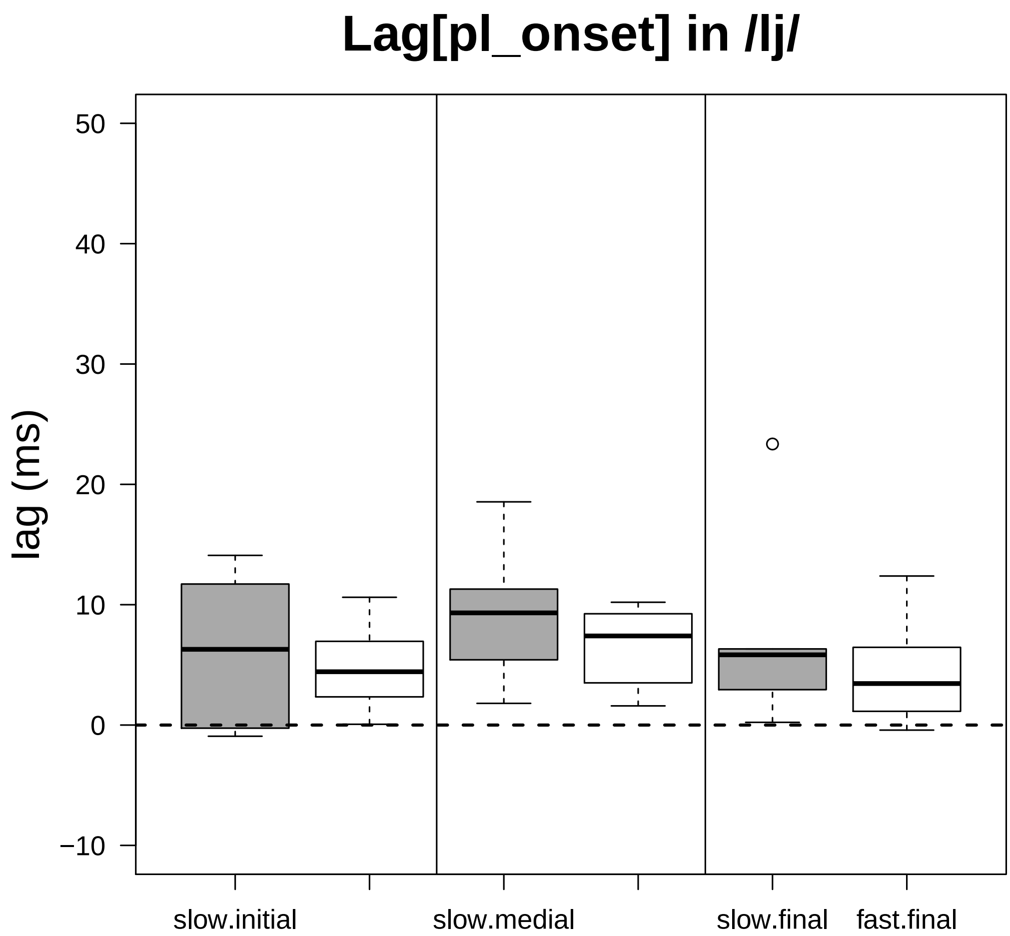


Figure 3.7: Lag between tongue dorsum and tongue tip plateau onsets in /lʲ/ at slow (grey) and fast (white) speech rates, in word-initial (left), -medial (middle), and -final (right) positions.

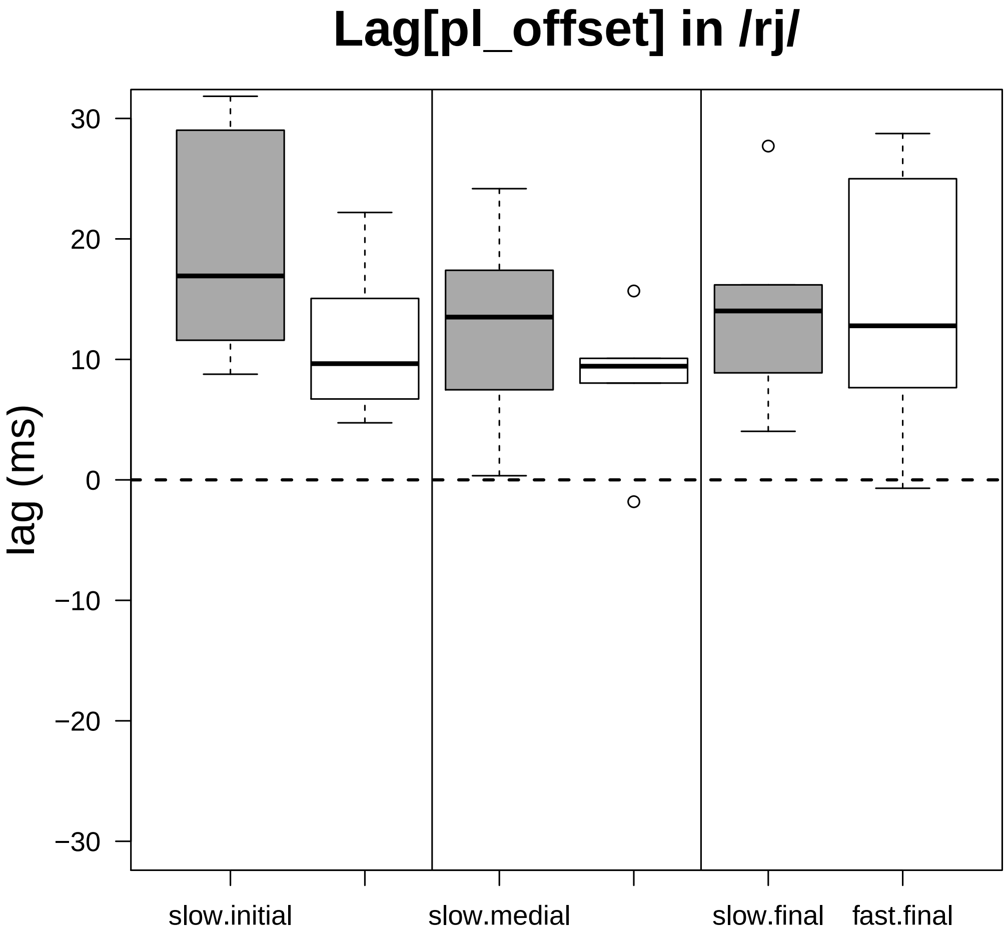


Figure 3.8: Lag between tongue dorsum and tongue tip plateau offsets in /r^j/ at slow (grey) and fast (white) speech rates, in word-initial (left), -medial (middle), and -final (right) positions.

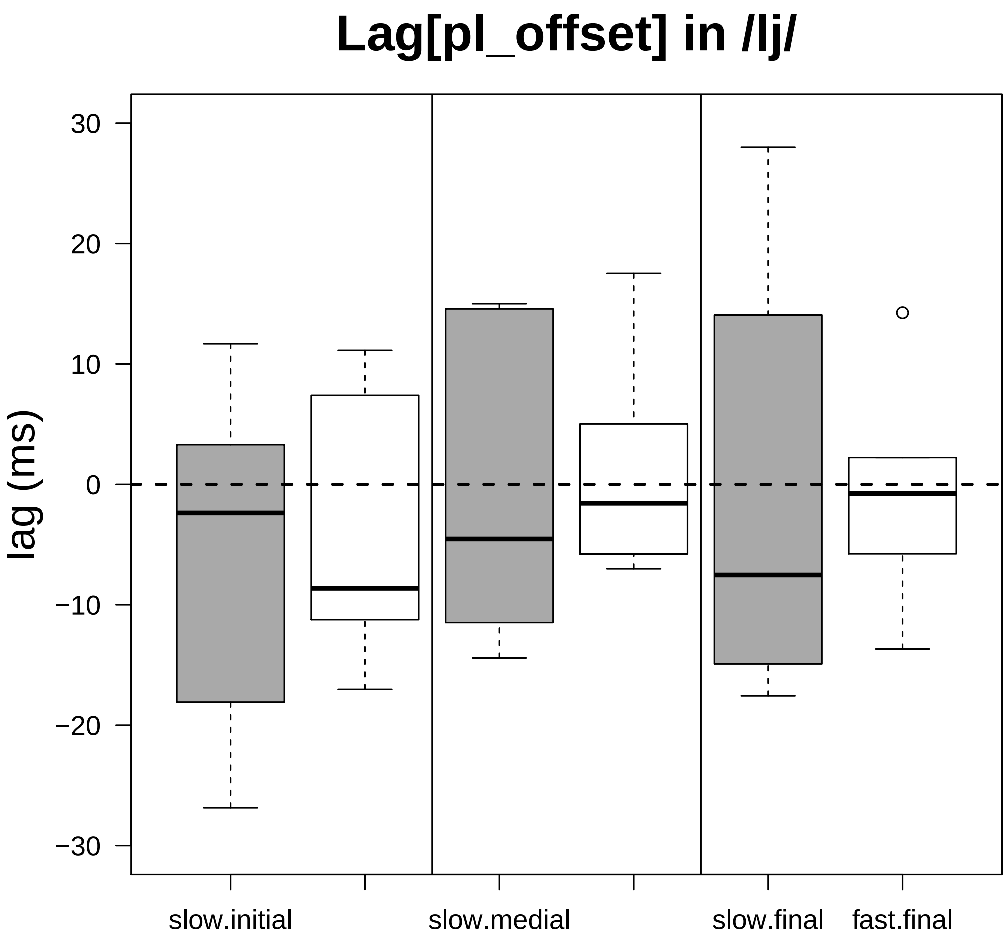


Figure 3.9: Lag between tongue dorsum and tongue tip plateau offsets in /l^j/ at slow (grey) and fast (white) speech rates, in word-initial (left), -medial (middle), and -final (right) positions.

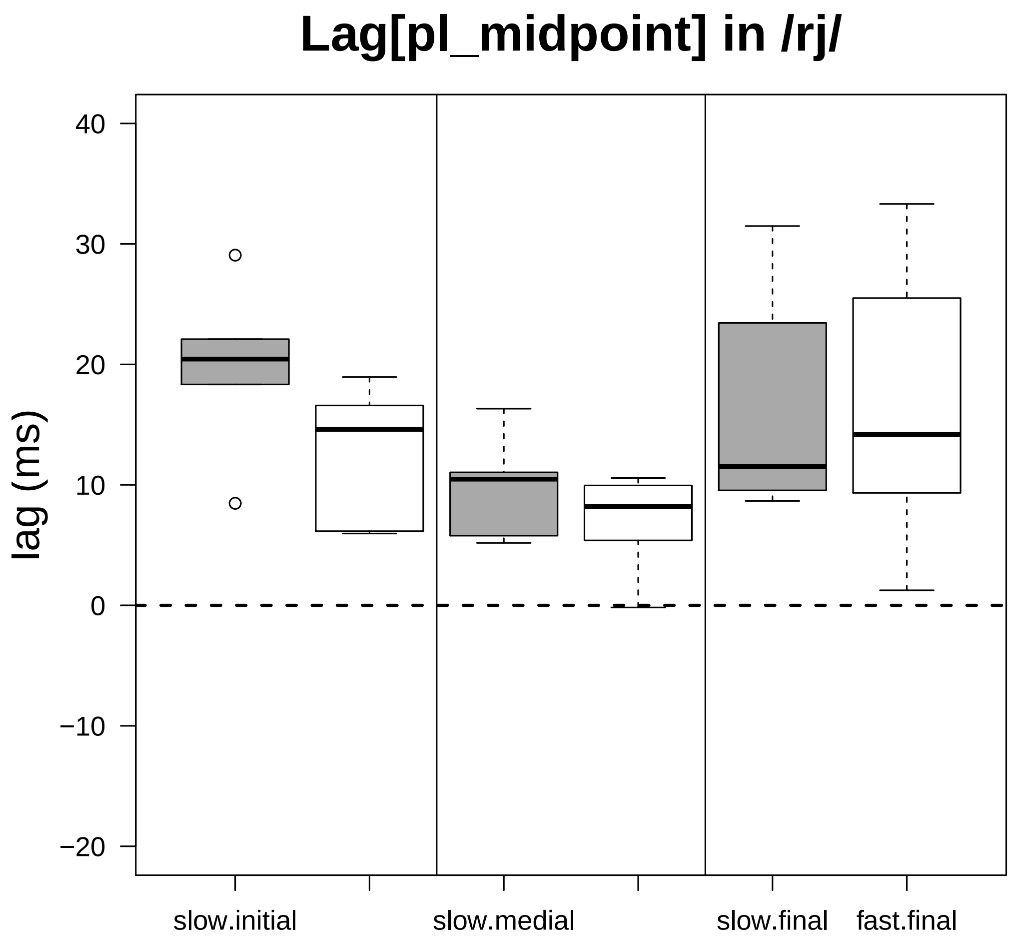


Figure 3.10: Lag between tongue dorsum and tongue tip plateau midpoints in /r^j/ at slow (grey) and fast (white) speech rates, in word-initial (left), -medial (middle), and -final (right) positions.

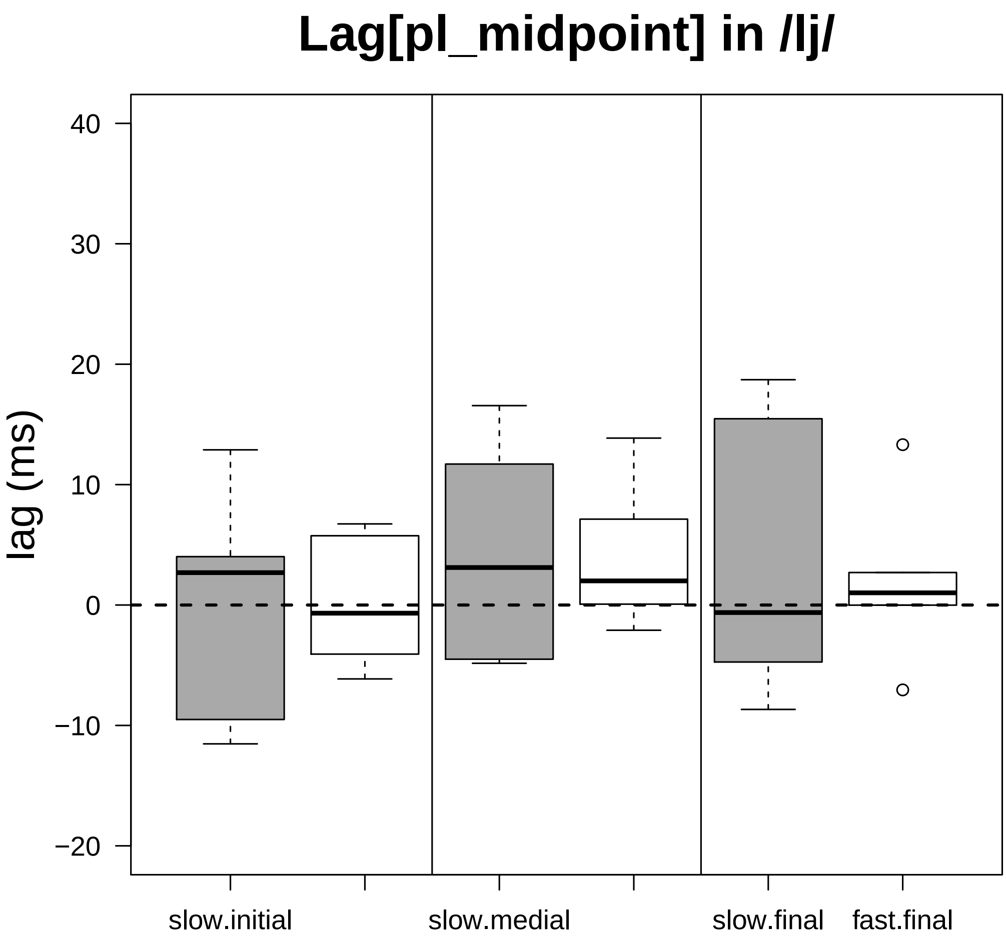


Figure 3.11: Lag between tongue dorsum and tongue tip plateau midpoints in /l^j/ at slow (grey) and fast (white) speech rates, in word-initial (left), -medial (middle), and -final (right) positions.

delayed with respect to the tongue tip at a slow rate ($p < 0.01$). The factor word position affects the $lag_{[midpoint]}$ in rhotics only: the $lag_{[midpoint]}$ is significantly greater in initial word position at a slow speech rate ($p < 0.001$) and with the same tendency at a fast speech rate ($p = 0.063$) than in medial position. No influence of speech tempo or word domain on the timing between primary and secondary gesture was found in /l^j/.

Summary

The present data confirm the previous findings (Kochetov 2005) that the secondary gesture is delayed in palatalised rhotics as compared to palatalised laterals. The novelty here is the extension of the analysis to other word positions (initial and medial). One interesting finding here is that the tongue dorsum is much more delayed in word-initial position at a slow speech rate in /r^j/ as compared to other positions and conditions. At the same time, /r^j/ has a much smaller lag in word-medial position and does not differentiate significantly from /l^j/ in this position. One possible explanation is that the tongue tip gesture in /r^j/ is stronger in word-initial position, while it is more reduced in word-medial position. Although the TT-plateau duration is the same in all word positions in /r^j/, it could be that /r^j/ is realised as a tap in word initial, but as an approximant in word-medial position. Another finding - a tendency of the TD-plateau to be reduced in medial position in /r^j/ - could be evidence that the palatalised rhotics tend to be reduced in this position, unlike in other word positions. It can be assumed that palatalised rhotics are more reduced in word-medial as compared to other word positions.

An informal look at the data suggests that the timing between the two gestures presents much variation in word-final position (across and within speakers) as compared to other word positions. This finding is in agreement with the framework of Articulatory Phonology, which suggests a tighter inter-gestural connection in CV than in VC sequences.

3.4.3 CV-overlap

Since the timing between the two gestures is sequential in /r^j/, the aim also was to analyse whether the secondary gesture in /r^j/ is more overlapped with the following vowel than in the case of /l^j/, word-initially. The reverse pattern is expected for coda position, i.e. less overlap between secondary gesture and preceding vowel in /r^j/ than in /l^j/. In order to investigate the overlap between the palatalisation gesture and the vowel, the distance between TD-plateau midpoint and anchor was measured.

Figure 3.12 shows the averaged distance between TD-plateau midpoint and anchor for /l^j/ and /r^j/ in initial and final word positions. A statistical analysis with the distance

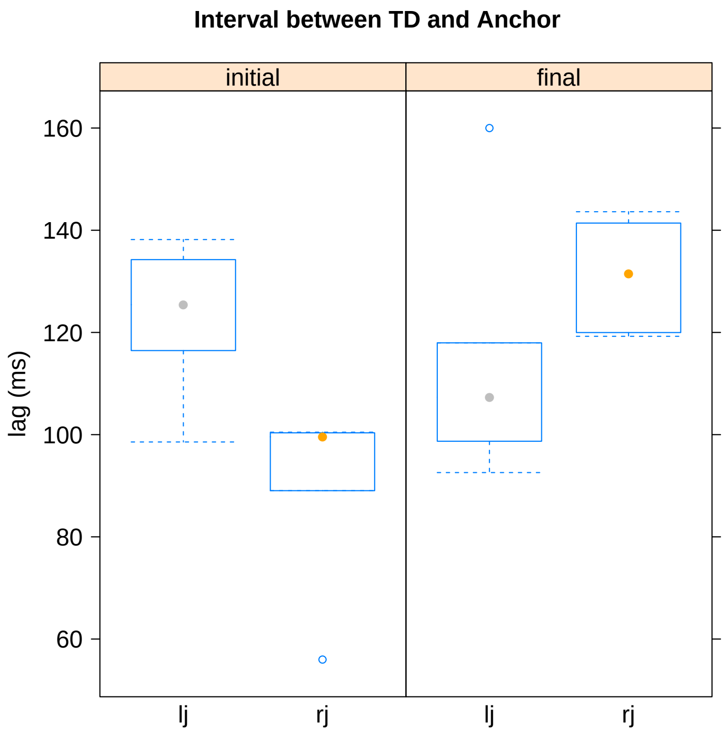


Figure 3.12: Distance (ms) between TD-plateau midpoint and anchor for /l^j/ (grey boxes) and /r^j/ (orange boxes) in initial (left) and final (right) word positions.

between TD-plateau midpoint and anchor as the dependent variable and liquid, position and speech rate as fixed factors revealed a main effect of speech rate ($F[1] = 31.4$, $p < 0.01$), and interaction between speech rate and liquid ($F[1] = 8.1$, $p < 0.01$) and between position and liquid ($F[1] = 284.8$, $p < 0.001$).

The post-hoc Tukey tests showed that the difference between rhotics and laterals was significant overall, the distance being smaller in word-initial position in /r^j/ than in /l^j/ ($p < 0.001$, mean difference = 33 ms), but the reverse was true in word-final position ($p < 0.05$, mean difference = 19 ms). Consequently, the factor word position only influenced palatalised rhotics, as the distance between the TD-plateau midpoint and the anchor was significantly smaller in initial than in final word position ($p < 0.001$). Unexpectedly, the distance between TD-plateau midpoint and anchor was similar in initial and final word positions in /l^j/. The factor speech rate had a significant influence in all contexts for both consonants: the distance was smaller at a faster speech rate ($p < 0.001$), meaning that the tongue dorsum overlaps more with the vowel at a faster than a slower speech rate.

By comparing the acoustic vowel duration after and/or before palatalised liquids (with liquid, word position, and speech rate as independent factors), it has been shown that the factor liquid had little main effect on the acoustic vowel duration ($F[1] = 9.5$, $p < 0.05$), the acoustic duration after and before /r^j/ being slightly greater than after/before /l^j/, as well as the speech rate ($F[1] = 32.7$, $p < 0.001$). The post-hoc Tukey tests revealed only a tendency in difference between /r^j/ and /l^j/ in vocalic duration ($p > 0.1$). Thus, although the tongue dorsum in /r^j/ overlaps more with the following vowel in word-initial position, but less in word-final position than in the case of /l^j/, the acoustic vowel duration is similar for both consonants (mean acoustic duration of /a/ in /l^j/-context = 97 ms and /r^j/-context = 104 ms).

In order to see how the vowel is influenced by palatalised consonants, consider Figure 3.13, where TD-positions in the temporal midpoint of the /a/-vowel are presented. It can be observed that the vowel is more fronted and raised when a palatalised rhotic precedes it. In contrast, the vowel seems to be slightly retracted and raised when followed by coda /l^j/, as compared to coda /r^j/, although the effect is less prominent.

F2 transitions

It has been hypothesised that the greater overlap between the tongue dorsum in /r^j/ and the following vowel should give rise to longer and more prominent vocalic transitions with higher F2 values as compared to /r^j/. In order to test this hypothesis, the second formant

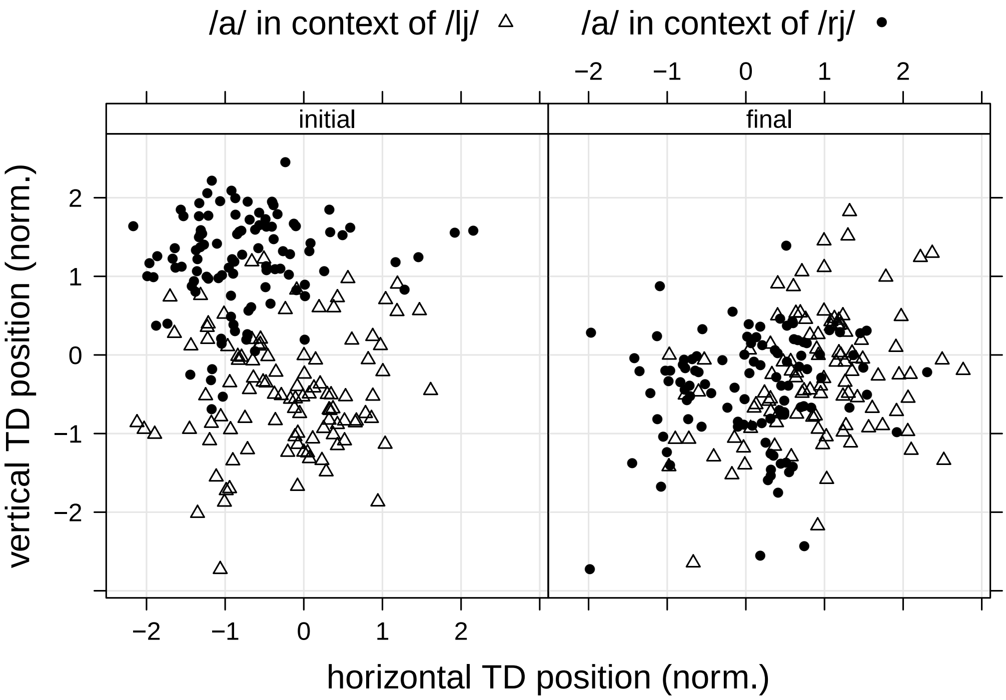


Figure 3.13: TD position in the temporal midpoint of /a/ vowel following (word-initially) or preceding (word-finally) /l^j/ and /r^j/.

Liquid	word-initial	word-final
$/r^j/$	1921	1730
$/l^j/$	1772	1625

Table 3.1: F2 values (in Hz), measured at 10 percent of the CV transitions and 90 percent of the VC transitions

values were measured in the first twenty percent of the F2 values in CV sequences (from the acoustic consonant offset to the vowel) and the final twenty percent in VC sequences (till the acoustic consonant offset). The second formant was chosen because it has been shown to be the most reliable acoustic correlate of palatalisation (Öhman 1966, Purcell 1979, Derkach et al. 1970, Kochetov 2005).

The statistical analysis with F2 transitions, normalised by the Lobanov technique, as the dependent variable and liquid ($/l^j/$ vs. $/l^j/$), word position (non final vs. final), and speech rate (slow vs. fast) as independent factors revealed the main effect of liquid ($F[1] = 12.7$, $p < 0.05$), word position ($F[1] = 58.6$, $p < 0.001$), and speech rate ($F[1] = 10.8$, $p < 0.05$). There was a two-way interraction between word position and speech rate ($F[1] = 5.2$, $p < 0.05$). The post-hoc Tukey tests showed that the F2 values are significantly greater in non-final $/r^j$a-/ than $/l^j$a-/ sequence at both speech rates ($p < 0.05$). The F2 transitions were greater in final /-ar^j/ than in /-al^j/ only at a slow speech rate ($p < 0.05$). Non final $/r^j$a-/ and $/l^j$a-/ transitions were higher than final /-ar^j/ and /-al^j/ transitions ($p < 0.001$). The factor speech rate had influence only in non final position, where the F2 transitions were higher at a slow than at a fast speech rate ($p < 0.01$).

Table 3.1 shows the mean F2 values measured at 10 percent of the CV transitions and 90 percent of the VC transitions between the consonant $/l^j/$ or $/r^j/$ and the vowel /a/ (the data are averaged for male and female speakers). It can be observed that the F2 values are greater after and before $/r^j/$, as compared to $/l^j/$. Figure 3.14 presents the normalised and averaged over all speakers F2 transitions for the whole vowel /a/. Although this asymmetry between the liquids has been predicted for word-initial position, it is not clear why the F2 values are greater in /a/ preceding the coda $/r^j/$ than that preceding $/l^j/$.

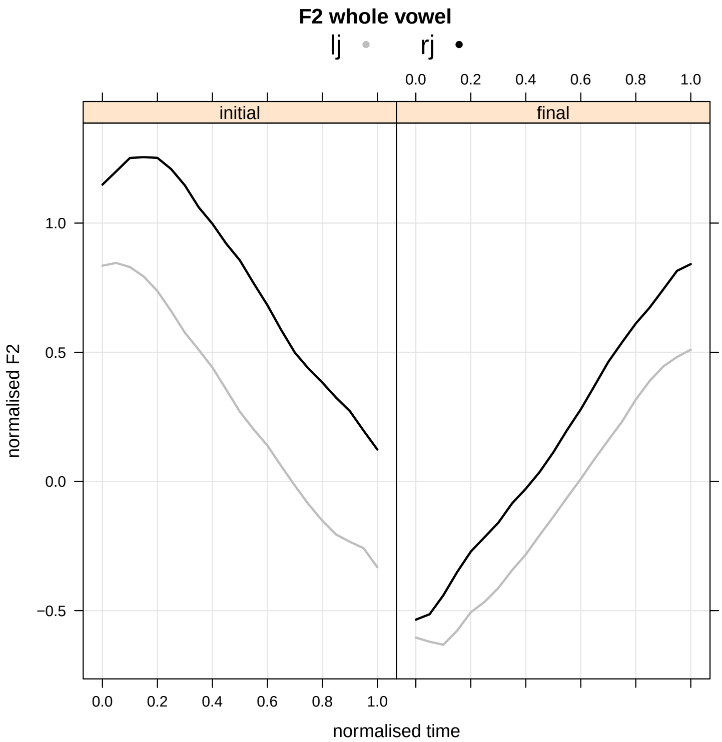


Figure 3.14: Normalised vocalic transitions in sequences /r^ja-/, /l^ja-/ (left) and in sequences /-ar^j/, /-al^j/ (right).

3.5 Discussion

3.5.1 General findings

The present study investigated the intergestural timing in palatalised rhotics and laterals and the temporal organisation between secondary gesture and the vowel in different word positions and at variable speech rates. First, the data confirmed and extended the previous findings that the timing between the two gestures is simultaneous in palatalised laterals, but the tongue dorsum is delayed in palatalised rhotics, in all word positions (Kochetov 2005; this is also in line with the acoustic analysis in Iskarous and Kavitskaya 2010). Secondly, the intergestural timing in rhotics, but not in laterals, was significantly influenced by word domain and speech tempo, meaning that it is less stable in the former than in the latter. Despite the variability, the timing in /r^j/ is always sequential: the tongue tip gesture is followed by the tongue dorsum raising.

However, a small lag between the tongue tip and tongue dorsum in rhotics word-medially raises the question of whether trilling and palatalisation can indeed be articulated simultaneously. One possible explanation for this finding could be the gestural undershoot in medial word position in comparison to the initial position, manifested probably in a less stiff tongue tip contact or less tongue dorsum raising. This undershoot would enable primary and secondary gestures to achieve their targets almost at the same time. In fact, the present analysis showed some evidence that the tongue dorsum in /r^j/ might be more susceptible to the influence of speech rate, word-medially. In addition, Iskarous and Kavitskaya (2010: 630) demonstrated that palatalised rhotics are realised as approximants more often in medial than in initial word position. The realisation of /r^j/ as an approximant rather than as a tap word-medially could be evidence of tongue tip gesture reduction.

In sum, the present findings are in line with the assumption that the trilling and palatalisation are incompatible (see Kavitskaya 1997, Kavitskaya et al. 2009): the trilling requires the tongue dorsum to lower and stabilise which is difficult or even impossible to achieve when the palatalisation gesture is added. Thus, palatalised rhotics have to present sequential intergestural timing in order to be properly articulated. However, the two gestures could potentially be articulated more simultaneously, which might be possible through gestural lenition. The results are far from being conclusive regarding this point; more research is needed in order to analyse how and whether the gestures are reduced.

3.5.2 Variation in timing

Partially contrary to what has been suggested previously (Byrd 1996a, 1996b, Browman and Goldstein 2000: 27), the timing between the two gestures in palatalised rhotics was more influenced by speech rate in initial than in final word position. However, the timing in word-final position presented greater interspeaker variation, unlike word-initially, where the pattern was similar across speakers. On the one hand, this is in line with previous findings that the word-final position is subject to less stability between gestures. The data on palatalised rhotics confirm the observation in Kochetov (2006a) about greater variability of sounds in word final position. On the other hand, a question arises: why is the tongue dorsum so much delayed in word initial position at all? One interpretation of this pattern could lie in perceptual recoverability (in line with Kochetov 2005, Chitoran et al. 2002, Gick et al. 2006; see below). Another potential explanation is that the highly delayed tongue dorsum gesture in /r^j/ word-initially at a slow speech rate could be an example of initial strengthening (see Fougeron and Keating 1997).

3.5.3 Articulatory Phonology (Browman and Goldstein 1995) and Sproat and Fujimura (1993): predictions on timing

It has been shown that /l^j/ and /r^j/ present similar patterns independently of word position: the two gestures are produced simultaneously in /l^j/ and sequentially in /r^j/ across the board. These results contrast with the predictions made by AP and Sproat and Fujimura (1993). The AP framework predicts nearly simultaneous timing between the two gestures in onset and sequential timing in coda position (Browman and Goldstein 1995). Sproat and Fujimura (1993) state, at least for English laterals, that the more vocalic dorsum gesture should occur near the syllabic nucleus, while the more consonantal gesture should be realised at the syllabic periphery. Neither prediction holds for palatalised laterals in Russian, which present simultaneous timing overall. Also contrary to the predictions in AP, it has been shown that the lag between the two gestures in /r^j/ is the greatest in initial position at a slow speech rate, revealing sequential timing between the two gestures. As far as laterals are concerned, the two gestures seem to be coupled more tightly when a language presents a phonological opposition between palatalised and plain consonants (as suggested in Gick et al. 2006 for Serbo-Croatian). Palatalised rhotics probably present an overall exception: their sequential timing is due to the particular articulatory constraints imposed on the tongue rather than to a specific syllabic organisation. Moreover, this asymmetry in rhotics may be explained in terms of perceptual recoverability (as already suggested in Kochetov 2005, Kochetov 2006a, see similar hypothesis in Chitoran et al. 2002 and Gick et al. 2006): word-initially, secondary palatalisation can be perceived almost only on C-to-V transitions. In word-medial position intervocalically, the hearer can perceive a palatalised rhotic on both V-to-C and C-to-V transitions.

The question arises as to how to handle the secondary articulation in languages with phonological contrast: is it a more vocalic gesture, as suggested by Sproat and Fujimura (1993), or do the two gestures present a cluster? It is not clear whether the two gestures are in-phased or anti-phased in /r^j/. Moreover, it is not clear why palatalised laterals and rhotics differ from palatalised labial plosives (which showed timing like predicted by Sproat and Fujimura 1993, see Kochetov 2006) and palatalised alveolar nasals (which showed sequential timing, see Recasens and Romero 1997). A broader and more uniform analysis is needed in order to clarify this issue.

CV-overlap

Another aim of the present study was to analyse how the complex sounds like palatalised consonants are organised in a syllable, i.e. with respect to the following or preceding vowel. The results reveal that, despite similar acoustic vowel duration, the tongue dorsum raising gesture presents greater overlap with the following vowel in /r^ja-/ than in /l^ja-/, word-initially. This finding is due to the fact that laterals are "prolongable" and may have greater duration, if necessary; for example, to host the secondary articulation. There is allegedly no conflict between laterality and palatalisation (see Kochetov 2005 for similar suggestion; also Hall 2000b). In palatalised rhotics, however, the overlap between the raised tongue dorsum and the following vowel is much greater. Recall that taps and trills can be seen as a sequence of one or several closing and opening phases. Palatalised rhotics usually present only one closed/open part (Iskarous and Kavitskaya 2010), and thus have a much shorter acoustic duration, unlike laterals. It can be observed in Figures 3.1 and 3.2 that the tongue dorsum raising target in /l^j/ is achieved quite early with respect to the consonant acoustic offset, while in /r^j/, the palatalisation target is posterior to the acoustic offset of the trill. This shows that laterals are "prolongable" even after their articulatory target is achieved. In addition, the finding that the acoustic vowel duration is similar in initial /r^ja-/ and /l^ja-/ sequences, but the tongue dorsum overlaps more with the following vowel in the former than in the latter suggests the following: the tongue dorsum gesture in /r^j/ can be seen as a more vocalic gesture (as predicted by Sproat and Fujimura 1993), even in a palatalised consonant where the actively raised tongue dorsum is an obligatory gesture.

3.5.4 Theoretical explanations for glide insertion

Sequential timing between primary and secondary gesture in trills may explain why one of the outcomes of /r^j/ is the sequence /rj/ before low vowels in Slovene, Lower Sorbian, and some dialects of Ukrainian (Carlton 1991, Greenberg 2000: 95-96, Stadnik 2002: 149, Jakobson 2002: 216).

Glide insertion in Articulatory Phonology

In the framework of AP, the glide insertion can be modelled as a change in the syllabic coupling relationship between tongue tip and tongue dorsum in a palatalised consonant. It could be hypothesised that the two gestures are in-phased in /l^j/ but anti-phased in /r^j/. As a result, the gestural coupling is looser in /r^j/, which gives rise to more often cases of "decomposition" of palatalised rhotics than laterals.

However, it is still not entirely clear how to explain the glide insertion depending on the speech rate in this framework. The Articulatory Phonology (1987 :17) predicts that

> [...] most of the phonetic units (gestures) that characterize a word in careful pronunciation will turn out to be observable in connected speech, although they may be altered in magnitude and in their temporal relation to other gestures. In faster, casual speech, we expect gestures to show decreased magnitudes (in both space and time) and to show increasing temporal overlap. We hypothesize that the types of casual speech alternations observed (segment insertions, deletions, assimiliations, and weakenings) are consequences of these two kinds of variation in the gestural score.

Indeed, the increased gestural overlap between the secondary gesture and the following vowel at a faster speech rate has been observed in the present study. However, the overlap between primary and secondary gestures has also increased at this condition, meaning than the two gestures are less sequential at a faster speech rate, compared to a slower speech rate. If the glide insertion should occur at a faster speech rate, it is not clear why the increased overlap between secondary gesture and the following vowel should have more weight for the perception than increased overlap between the primary and secondary gestures. A tentative explanation could be that although the lag between the two gestures is smaller at a faster speech rate in /r^j/, it is still positive, meaning that the tongue dorsum is still slightly delayed with respect to the tongue tip.

Glide insertion in the DAC-model

Recasens (2014: 28) also sees the reason for the glide insertion in the sequential timing in palatalised consonants and prominent vocalic transitions. For Recasens, however, precisely the more emphatic articulation, which is expected at a slower speech rate, is likely to highlight the vocalic transitions. In such case, listeners are even more aware of the F2 transitions and would interpret them as a separate sound:

> Glide insertions and elisions are also dependent on consonant reinforcement: an increase in constriction degree gives rise to more prominent vowel transitions and consonant releases, thus increasing the chances that the former acoustic cue is integrated as a glide and that reduced glides cease to be heard (Recasens 2013c: 112).

In line with this assumption, the present study showed that the delayed tongue dorsum gesture and its greater overlap with the following vowel in /r^j/, unlike /l^j/, is responsible for higher F2 values in CV transitions, especially at a slower speech rate. A perceptual analysis would be necessary in order to analyse whether and how the variation in speech rate might influence the perception of a glide in /r^{j}a-/ sequence.

On the other hand, there could probably be another reason for prevalence of the cases of glide insertion after palatalised trills than after palatalised laterals. Recasens compares palatal /ʎ/, /ɲ/ and /c/ in Romance languages and claims that while /ʎ/, /ɲ/ often present an anticipatory glide insertion, /c/ almost in all cases has a following glide insertion. For the author, the following glide insertion in /c/, but not so in /ʎ/ and /ɲ/ is due to the fact that in /c/ "the lowering movement takes a longer time, proceeds more slowly and ends at a higher articulatory position as tongue dorsum contact for the consonant increases" (Recasens 2013c: 114). Extending this thought to the present case: if the tongue body lowers more slowly in palatalised trills, this could be another reason for glide insertion.

All three theories would predict that the glide insertion after a palatalised rhotic is due to the delayed tongue dorsum gesture and its greater overlap with the following low vowel, which likely have more prominent F2 transitions as an acoustic consequence. These prominent transitions could eventually be seen as intentional: the listener could interpret them as a separate sound /j/ (Recasens and Espinosa 2010, Recasens 2013c, Ohala 1981).

Chapter 4

Influence of palatalisation on tongue tip in liquids

Summary

This chapter deals with the influence of secondary palatalisation on tongue tip in rhotics and laterals. It has been mentioned in the literature that taps are articulated with very fast tongue tip movements, although it has not been investigated broadly so far (Ladefoged and Maddieson 1996: 232). Moreover, it is not clear whether this argument holds for alveolar trills as well. First, what will be analysed is whether the trills indeed involve a very fast tongue tip movement during the closing gesture[1] as compared to laterals and, second, whether the tongue tip velocity will be impaired by palatalisation in the former. In order to address these issues, the tongue tip velocity, maximum displacement, and stiffness in plain and palatalised liquids /l/, /lʲ/, /r/, and /rʲ/ of Russian are compared. The results show, first, that rhotics present greater tongue tip peak velocity and stiffness, as compared to laterals. Second, palatalisation has an opposite effect on the peak velocity in laterals and rhotics: the peak velocity is less in a palatalised rhotic but greater in a palatalised lateral as compared to their plain counterparts. It is hypothesised that a slower and less stiff tongue tip in /rʲ/ as compared to /r/ could be one of the articulatory reasons behind the sound change /rʲ/ > /r̝/ > /ʒ/, which took place in Czech and Polish.

[1]Tongue tip "closing gesture" refers here to the movement from the rest position to the consonant target position.

4.1 Introduction

4.1.1 Sound change in Czech and Polish

While in some Slavic languages the palatalised rhotic lost its secondary gesture and changed to a plain trill (e.g. Belarusian, Carlton 1991: 299), languages like Czech and Polish experienced the process of spirantisation: the trilling was partially or completely lost. It is assumed that the palatalised rhotic changed to the trill-fricative /r̝/ in Czech and at the earlier stages of Polish. Studies suggest that this sound change took place both in Czech and Polish at nearly the same time (see Żygis 2005, Stieber 1973: 49). Unlike in Czech, which still preserves this sound, the trill-fricative changed later to the voiceless or voiced post-alveolar fricative, depending on the condition in Polish.

4.1.2 Phonetics of trill-fricatives

Czech is the most famous example of a language which has the trill-fricative /r̝/ in its phonemic inventory, a rhotic which is produced with the tongue blade (Ladefoged and Maddieson 1996: 228).[2] Ladefoged and Maddieson (1996: 228-229) state that "this trill is typically made with the laminal surface of the tongue against the alveolar ridge", and the trilling is followed by a short period of frication. For Laver (1994: 264), fricative trills are produced when the contact between the tongue and the alveolar ridge is not complete, and the air escapes continuously from the mouth cavity rather than periodically as in an alveolar trill. This irregular continuity in the airflow would produce an impression of trilling accompanied by friction.

Howson et al. (2015) used EMA to analyse the cross-sectional tongue morphology of Czech fricatives and trills. The authors found out that the articulation of post-alveolar fricatives /ʒ/, /ʃ/ and of both the alveolar trill /r/ and the trill-fricative /r̝/ are similar in that these sounds are articulated with little tongue grooving, unlike alveolar fricatives /s/ and /z/. The flat tongue dorsum articulation may be due to the lateral tongue bracing, which is suggested as an additional means of stabilising the tongue and allowing the tongue tip to vibrate (Howson et al. 2015, McGowan 1992).

Thus, a similar tongue position and the audible friction in fricative-trills may explain the change from /r̝/ to /ʒ/ and /ʃ/ in Polish. The present study, however, aims at investigating

[2] Some dialects of Latin American Spanish probably also present this sound, which is a regional realisation of the standard Spanish /r/ (Whitley 2003, Alonso 1967).

the articulatory preconditions for the change from the palatalised rhotic /rʲ/ to the trill-fricative /r̝/. Considering the fact that alveolar trills require several conditions to be met in order for the tongue tip to vibrate (Ladefoged and Maddieson 1996, Kavitskaya 1997, Solé 2002), the disturbance of these necessary conditions (e.g. though secondary articulation) could lead to the impairment or cessation of trilling.

4.1.3 Tongue tip velocity in rhotics and laterals

As it has been described in the introduction chapter, the articulation of alveolar rhotics requires a precise articulatory control over the tongue. What, however, about the tongue tip velocity? Several studies have shown that the tongue tip vibration is quite a fast process and presents a similar duration and frequency in unrelated languages: the acoustic duration of one cycle is approximately 40-50 ms (counting the open and closed phases), which corresponds to the frequency of vibration of 25-28 Hz in alveolar voiced trills (Lindau 1985, Ladefoged and Maddieson 1996: 218, Ladefoged et al. 1977). It would be intuitive to assume that the tongue tip should move very fast overall, also during the closing and opening gestures. Several authors indeed mention that at least taps involve a quick ballistic tongue tip movement (Ladefoged and Maddieson 1996: 232, Recasens and Espinosa 2007: 1, Solé 1999). For Hall and Hamann (2010)[3] and Hamann (2003), all apical consonants present a very rapid gestural movement, "as the tongue tip is the most flexible and quickest active articulator" (Hamann 2003: 33).

However, the empirical evidence for this observation is scarce. Hoole et al. (2013) and Pouplier and Beňuš (2011) analysed Slovak syllabic and non-syllabic rhotics and laterals and found out that the peak velocity was higher in the former. Howson and Kochetov (2015) found a similar pattern in Czech alveolar trills and laterals[4]: the tongue tip in trills was approximately 100 mm/s faster than in laterals (ca. 250 mm/s and 150 mm/s, respectively). In the same line, Scobbie et al. (2013: 111-112) found in an ultrasound study of a single speaker of Malayalam (a Dravidian Language) that the peak velocity in the closing gesture in trills was ca. 250 mm/s, while the clear lateral presented the peak velocity of 100-150 mm/s. Interestingly, the retroflex lateral /ɭ/ of Malayalam presented a

[3]Hall and Hamann (2010) state this for apical trills in general, but cite Solé (1999) who, however, only claims it for taps.

[4]The authors use the term "trill" although the realisation of Czech trills is also highly variable; as in Russian, Czech alveolar trills often present only one cycle (Šimáčková et al. 2012). Besides, Czech laterals seem to be less velarised and present more positional variation than Russian laterals (Ščerba 1911: 283, Recasens 2012a, Howson and Kochetov 2015).

high peak velocity, comparable to rhotics, with a “closing speed of 200 mm/s and a forward flapping speed of around 400 mm/s” (Scobbie et al. 2013: 112).

Although the previous studies suggest that trills and taps have a fast tongue tip closing gesture, it is not clear whether it is one of necessary conditions for trilling. Since lingual trills are very sensitive sounds, any disturbance of the articulatory or aerodynamic conditions could result in the cessation of trilling. In what follows, the tongue tip velocity in Russian liquids will be analysed in more detail, while the relative importance of this aspect for the production of trills will be discussed in more detail in the last section.

4.1.4 Peak velocity, maximum displacement, and stiffness

In order to investigate the influence of the secondary palatalisation on the tongue tip gesture in rhotics and laterals, the tongue tip closing gesture was analysed.[5] In particular, the tongue tip peak velocity in the closing gesture, the tongue tip maximum displacement from the gesture onset to the gesture target, and the relation between the peak velocity and the maximum displacement were measured.

The peak velocity, i.e. the maximum velocity the tongue tip achieves during the closing gesture, is the focus of the present analysis. However, the pure peak velocity might not be a reliable measure, since it might vary depending on the total distance the articulator has to cover, on changes in speech rate or on the presence or absence of word stress (see Gay 1981, Kent and Moll 1972, Kelso et al. 1985, Ostry and Munhall 1985). In order to normalise the peak velocity, the ratio of the peak velocity to the maximum displacement, or *stiffness*, was calculated (Ostry and Munhall 1985, Munhall et al. 1985, Browman and Goldstein 1990a, Kühnert and Hoole 2004, Roon et al. 2007, Peters 2015, etc.). In the framework of Articulatory Phonology, “the stiffness of a gesture determines how fast the specified target is achieved” (Nam et al. 2012). It is important to bear in mind that the term “stiffness” used in the present study refers to the articulator oscillation rather than the muscular activity (articulator stiffness, Perkell et al. 2002: 1629).

The term stiffness forms part of the modelling in Articulatory Phonology, although it has not been used extensively so far. It has been suggested that consonants and vowels may differ in stiffness: the consonants present a faster tongue movement than the vowels do and, thus, have higher stiffness values (Browman and Goldstein 1990a, 1992). It has been also proposed that natural classes of sounds may differ in stiffness. For example, plosives may

[5] The term “closing gesture” refers to the tongue movement from the rest position to the target position. In trills, the target is the position where the tongue tip would start to vibrate due to the Bernoulli effect.

present a stiffer tongue gesture than fricatives (See Löfqvist 2005 on empirical evidence for the difference between plosives and fricatives).

Since laterals and rhotics belong to the natural class of liquids, it could be assumed that they would present similar tongue tip stiffness. However, Proctor (2009) uses different stiffness values in the TADA modulation of Spanish and Russian trills and laterals.[6] Parrell et al. (2010) report that they successfully modelled in TADA the difference between Spanish tap and trill by manipulating the stiffness. It seems as though more research needs to be done in order to find out how consonants differ in stiffness and whether it is a useful measure.

4.2 Hypotheses

The following hypotheses will be investigated here:

H1: Trills present a fast tongue tip closing gesture as compared to laterals. It is expected that both absolute values of peak velocity and normalised peak velocity (stiffness) are higher in the former, as already reported or suggested for other languages (Hoole et al. 2013, Howson and Kochetov 2015, Scobbie et al. 2013, Proctor 2009).

H2: The palatalisation has a reduced influence on the tongue tip peak velocity and stiffness in rhotics because it is antagonistic to the requirements for trilling (Ladefoged and Maddieson 1996, Kavitskaya 1997). Due to the fact that the tongue dorsum has to retract and to stabilise in order to assure the trilling, the necessity of the tongue dorsum to be raised for palatalisation would have detrimental consequences for vibration. This could be one of the articulatory explanations for the sound change /r^j/ into /r̝/.

H3: In contrast, the palatalisation has no influence on the tongue tip velocity and stiffness in laterals. Secondary articulation, like palatalisation or velarisation, seems to cope well with laterality (Broch 1910, Kochetov 2005). Thus, no conflict between tongue tip and tongue dorsum gestures is expected in palatalised laterals.

[6] TADA (Task Dynamics Application, Nam et al. 2004) is a software based on a coupled-oscillator model and gestural-coupling model, which allows artificial modelling of speech.

4.3 Method

4.3.1 Speech material

The data used in the present analysis are part of the articulatory experiment described in Chapter 2. The palatalised and plain liquids /l^j/, /l/, /r^j/, and /r/, followed by stressed vowels /a/, /i/ or /u/ will be investigated. Since the peak velocity, maximum displacement and stiffness can potentially be influenced by conditions like phonetic context or word stress, only the data from the initial word position will be analysed here. It was important to have labial consonants in the proximity of the target consonant, since the former do not require the active tongue tip activation and, thus, do not interfere with the articulation of the latter (Ladefoged and Maddieson 1996: 364). Hence, the data of the first participant were excluded from the analysis because of a different carrier sentence in the pilot study. This way, the target consonants are always preceded by the sequence labial consonant plus low unstressed vowel /-va/ of the carrier sentence.

4.3.2 Measurements

Several measurements were calculated in the present analysis.[7] First, the tangential peak velocity[8] during the closing gesture, i.e. during the tongue tip movement from gesture onset to maximum constriction, was measured. Second, the maximum tongue tip displacement was calculated as the distance between the tongue tip gesture onset and the constriction plateau onset in a two-dimensional space (horizontal and vertical)[9]. Third, the stiffness as the ratio of peak velocity to maximum displacement (Munhall et al. 1985, Roon et al. 2007) was calculated:

(1) Stiffness (1/s) = tangential peak velocity (mm/s) / maximum displacement in a two dimensional space (mm)

Statistical analysis

The statistical analysis with liquid (two levels: lateral vs. rhotic), palatalisation (two levels: palatalised vs. plain), and speech rate (two levels: slow vs. fast) as fixed factors

[7]The detailed description of the data analysis and labelling is provided in Chapter 2.

[8]Tangential velocity is the sum of vertical and horizontal velocities.

[9]Note that the plateau onset (measured as 20 % threshold of the velocity change), and not the maximum constriction (when the velocity is equal to zero), was chosen because the former presents a more stable measure.

and speaker (speakers V2-V6) as the random factor was performed with linear mixed models and post-hoc Tukey tests using package lmerTest in R.

4.4 Results

In Figure 4.1, the tongue tip peak velocity in palatalised and plain laterals and rhotics is displayed. It can be observed that the peak velocity is higher in rhotics than in laterals overall (mean values for /l/: 150 mm/s, /l^j/: 249 mm/s vs. /r/: 366 mm/s, /r^j/: 318 mm/s). Plain rhotics exhibit the highest peak velocity, while plain (velarised) laterals exhibit the lowest peak velocity. The mixed models analysis with peak velocity as the dependent variable and liquid, palatalisation, and speech rate as fixed factors showed a significant effect of liquid ($F[1] = 101.4$, $p < 0.001$), palatalisation ($F[1] = 8$, $p < 0.05$), and an interaction between liquid and palatalisation ($F[1] = 146.9$, $p < 0.001$) and between liquid and speech rate ($F[1] = 5.5$, $p < 0.05$). The post-hoc Tukey tests revealed that the four consonants present a significantly different peak velocity ($p < 0.01$). Remarkably, palatalised and plain rhotics and laterals exhibit an asymmetrical pattern: while the tongue tip peak velocity is significantly higher in the plain trill as compared to its palatalised counterpart, the peak velocity is lower in /l/ as compared to /l^j/.

Figure 4.2 shows the data on peak velocity for palatalised and plain liquids for each speaker separately. It can be observed that all speakers present the same pattern as in Figure 4.1: the peak velocity is the greatest in plain rhotics and the smallest in plain laterals. In all speakers, the tongue tip peak velocity in rhotics decreases when the secondary gesture is added. However, the peak velocity is higher in a palatalised lateral as compared to its plain counterpart.

Figure 4.3 shows that the tongue tip maximum displacement[10] in the closing gesture is similarly high in /r/, /r^j/, and /l^j/, unlike in /l/ (mean values: 10.3 mm, 10 mm, 10 mm and 7.4 mm, respectively). The statistical analysis of the maximum displacement indicated the main effect of liquid ($F[1] = 12.2$, $p < 0.05$), a small influence of palatalisation ($F[1] = 6.3$, $p = 0.05$), and an interaction between liquid and palatalisation ($F[1] = 81.5$, $p < 0.001$), between liquid and speech rate ($F[1] = 18.8$, $p < 0.001$), and a three-way interaction between liquid, palatalisation and speech rate ($F[1] = 8.5$, $p < 0.01$).

The post-hoc Tukey tests showed that the maximum displacement was significantly

[10]Remember that the maximum displacement was measured in a two dimensional space: vertical and horizontal displacement.

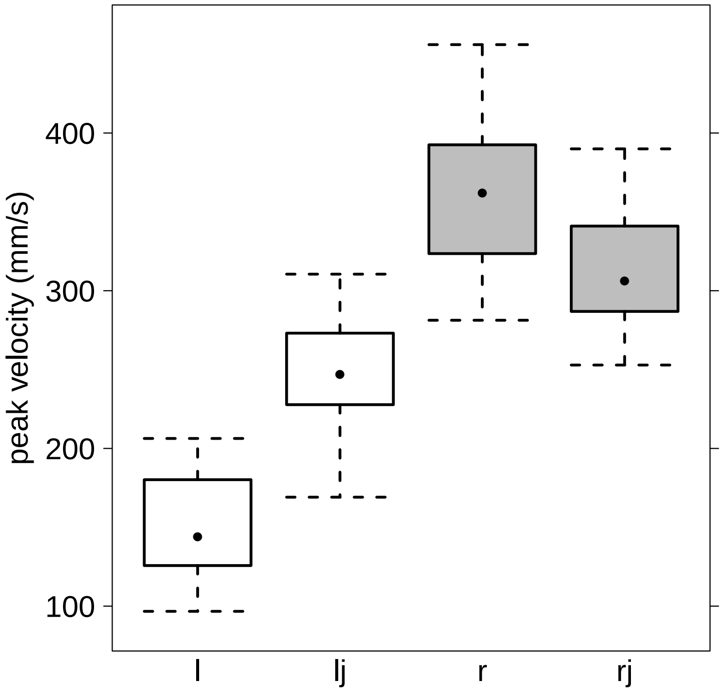


Figure 4.1: Tongue tip peak velocity in the closing gesture in plain and palatalised laterals (white) and rhotics (grey).

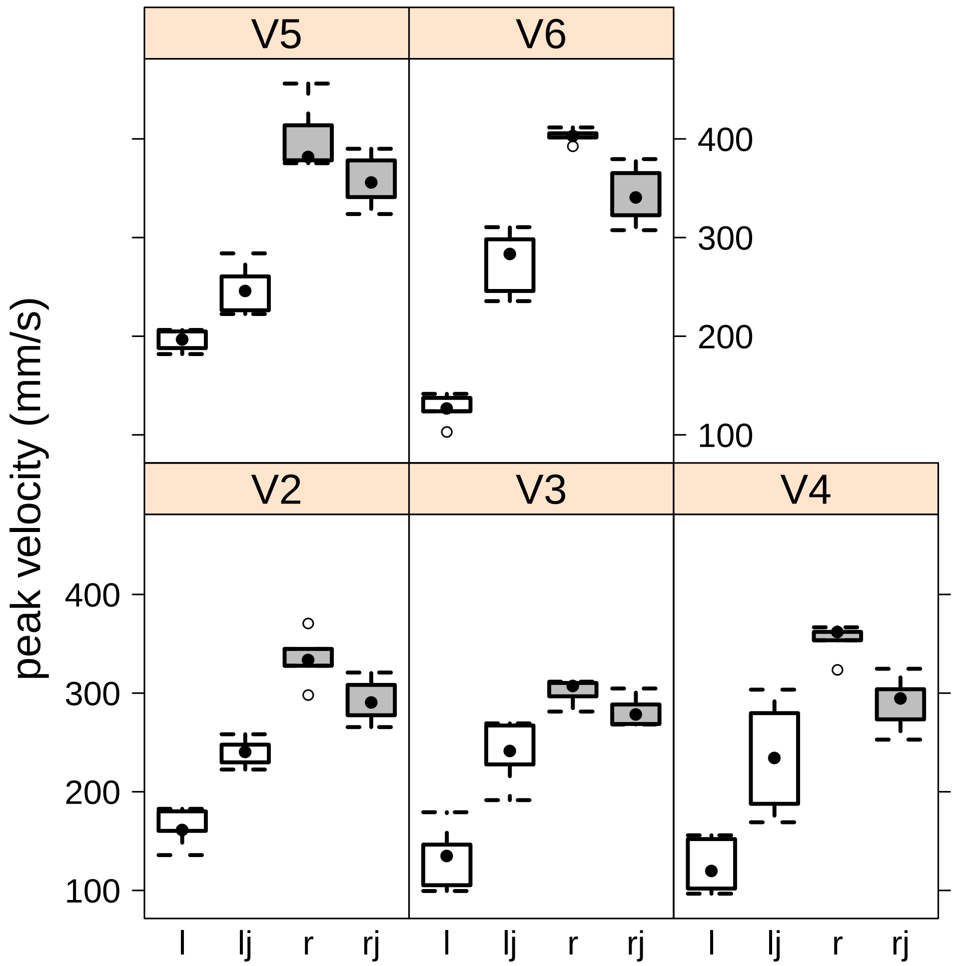


Figure 4.2: Tongue tip peak velocity in plain and palatalised laterals (white) and rhotics (grey) separately for each speaker.

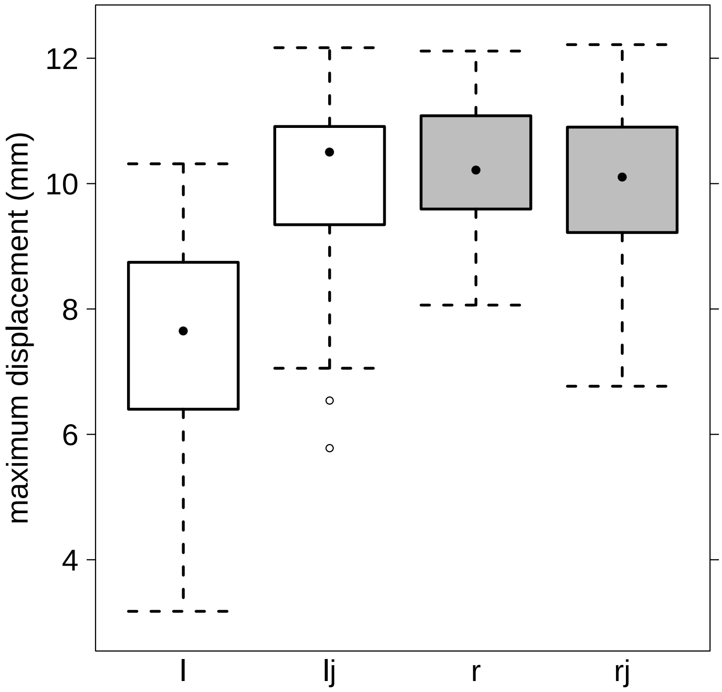


Figure 4.3: Tongue tip maximum displacement in plain and palatalised laterals (white) and rhotics (grey).

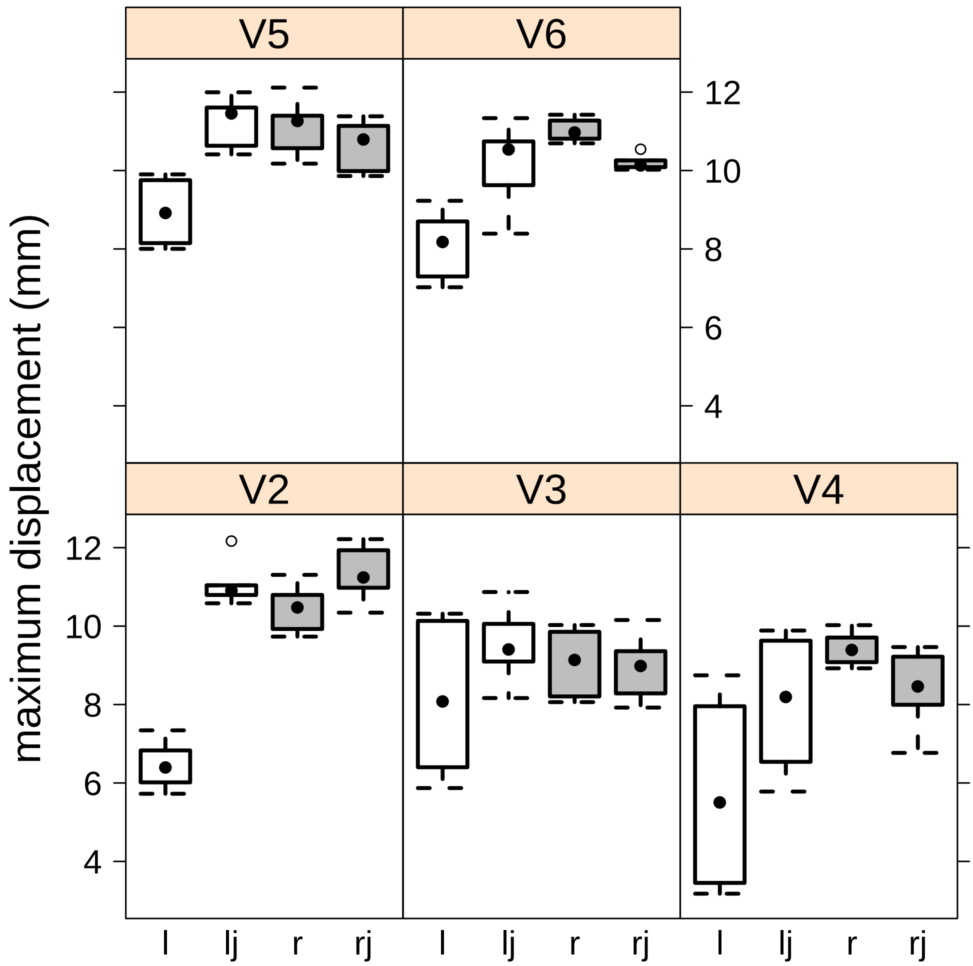


Figure 4.4: Tongue tip maximum displacement in plain and palatalised laterals (white) and rhotics (grey) separately for each speaker.

smaller in /l/ as compared to /r/, /r^j/ and /l^j/ ($p < 0.001$). There was no significant difference between /r/, /r^j/ and /l^j/ ($p > 0.1$). The factor speech rate had an influence only on the tongue tip displacement in /l/ (smaller tongue tip displacement at faster speech rate, $p < 0.01$).

Figure 4.4 presents the data on tongue tip maximum displacement for each speaker separately. All speakers exhibit a similar pattern; however, the data from the participants V3 and V4 display much variation in maximum displacement in /l/.

Finally, the results on tongue tip stiffness, i.e. the ratio between the peak velocity and maximum displacement, are presented in Figure 4.5. It can be observed that the stiffness difference between consonants resembles the pattern observed in peak velocity data (Figure 4.1). In general, the tongue tip is stiffer in rhotics than in laterals. Moreover, plain rhotics seem to present higher tongue tip stiffness as compared to their palatalised counterparts (mean values: 35.6 1/s and 32.5 1/s, respectively). Although the mean values of the tongue tip stiffness are smaller in /l/ than in /l^j/ (21.3 1/s and 25.4 1/s, respectively), the stiffness values in /l/ present a considerable variation and overlap with the /l^j/-category.

The statistical analysis indicated a significant influence of liquid ($F[1] = 43.1$, $p < 0.001$), speech rate ($F[1] = 13.8$, $p < 0.05$), and an interaction between liquid and palatalisation ($F[1] = 30.5$, $p < 0.001$), between palatalisation and speech rate ($F[1] = 12.1$, $p < 0.001$), and three-way interactions between liquid, palatalisation and vowel ($F[2] = 3.6$, $p < 0.05$), and between liquid, palatalisation, and speech rate ($F[1] = 23.3$, $p < 0.001$). The post-hoc Tukey tests showed that the difference in stiffness between rhotics and laterals was significant overall (at both slow and fast speech rates, $p < 0.01$). There is no statistical difference in stiffness between palatalised and plain rhotics ($p > 0.1$). At a slow speech rate, the palatalised laterals exhibit a higher stiffness as compared to /l/ ($p < 0.05$). The speech rate has an influence on the tongue tip stiffness in /l/ (stiffer tongue tip at a faster speech rate, $p < 0.001$). In palatalised rhotic, the tongue tip is only marginally stiffer at a faster than at a slower speech rate ($p = 0.05$).

Figure 4.6 shows the tongue tip stiffness data for each speaker separately. Although all speakers exhibit a tendency to have a stiffer tongue tip in plain trills than in palatalised ones (resembling the pattern on peak velocity), the post-hoc Tukey tests indicated no significant difference. In can be seen in Figure 4.6 that only speaker V2 and V6 present a clearly different stiffness between /r/ and /r^j/. The previous analysis carried out on the subset of the present data including only the context of /a/-vowel (Stoll et al. 2016), indicated a significant difference between /r/ and /r^j/ both in peak velocity and stiffness.

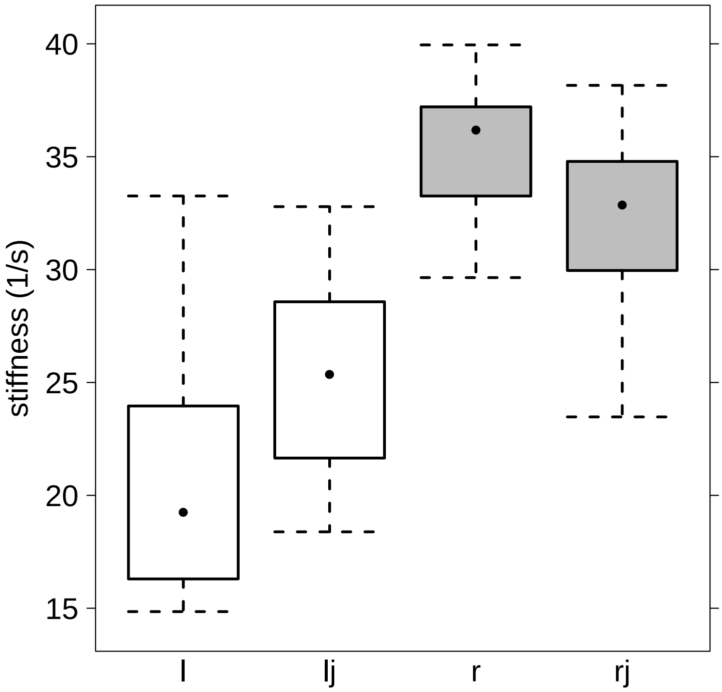


Figure 4.5: Tongue tip stiffness in plain and palatalised laterals (white) and rhotics (grey).

An alternative analysis with a vowel as the fixed factor (not reported here) revealed no significant effect of vocalic context on stiffness. The reason behind the absent statistical significance in the difference between /r/ and /r^j/ could lie in the high number of fixed factors in the present analysis and the interaction between them, which might produce less significant data in post-hoc analysis.

The difference in stiffness between laterals is not as straightforward as in the case of rhotics. While there is a clear tendency for /l^j/ to present a higher stiffness than in /l/ for speaker V3, V4, and V6, speaker V5 exhibits similar stiffness in both laterals. Speaker V2 even has a higher tongue tip stiffness in /l/ than in /l^j/, which could be due to the comparatively smaller difference in peak velocity and greater difference in maximum displacement between /l/ and /l^j/ for this speaker. Figure 4.7 illustrates both peak velocity and maximum displacement in the same graph, averaged over speaker and consonant (one token of each consonant per speaker).

In sum, the data confirm the hypothesis that the tongue tip peak velocity and stiffness

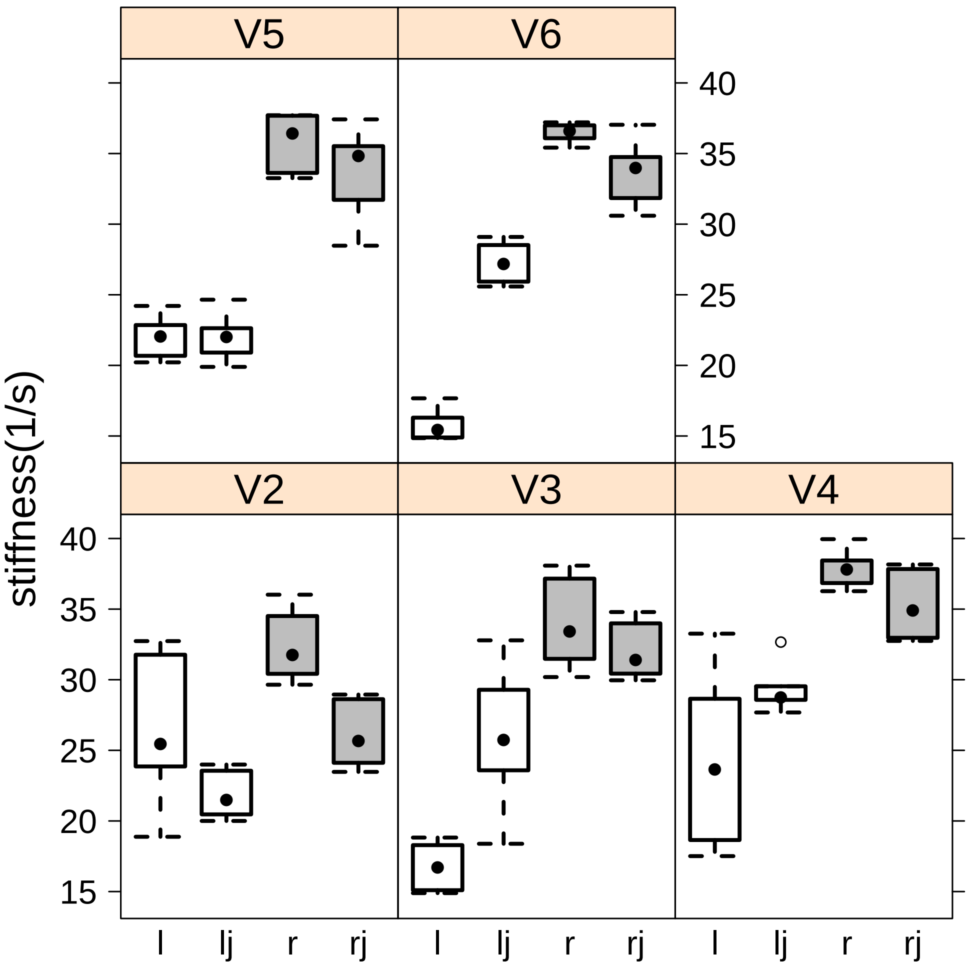


Figure 4.6: Tongue tip stiffness in plain and palatalised laterals (white) and rhotics (grey), separately for each speaker.

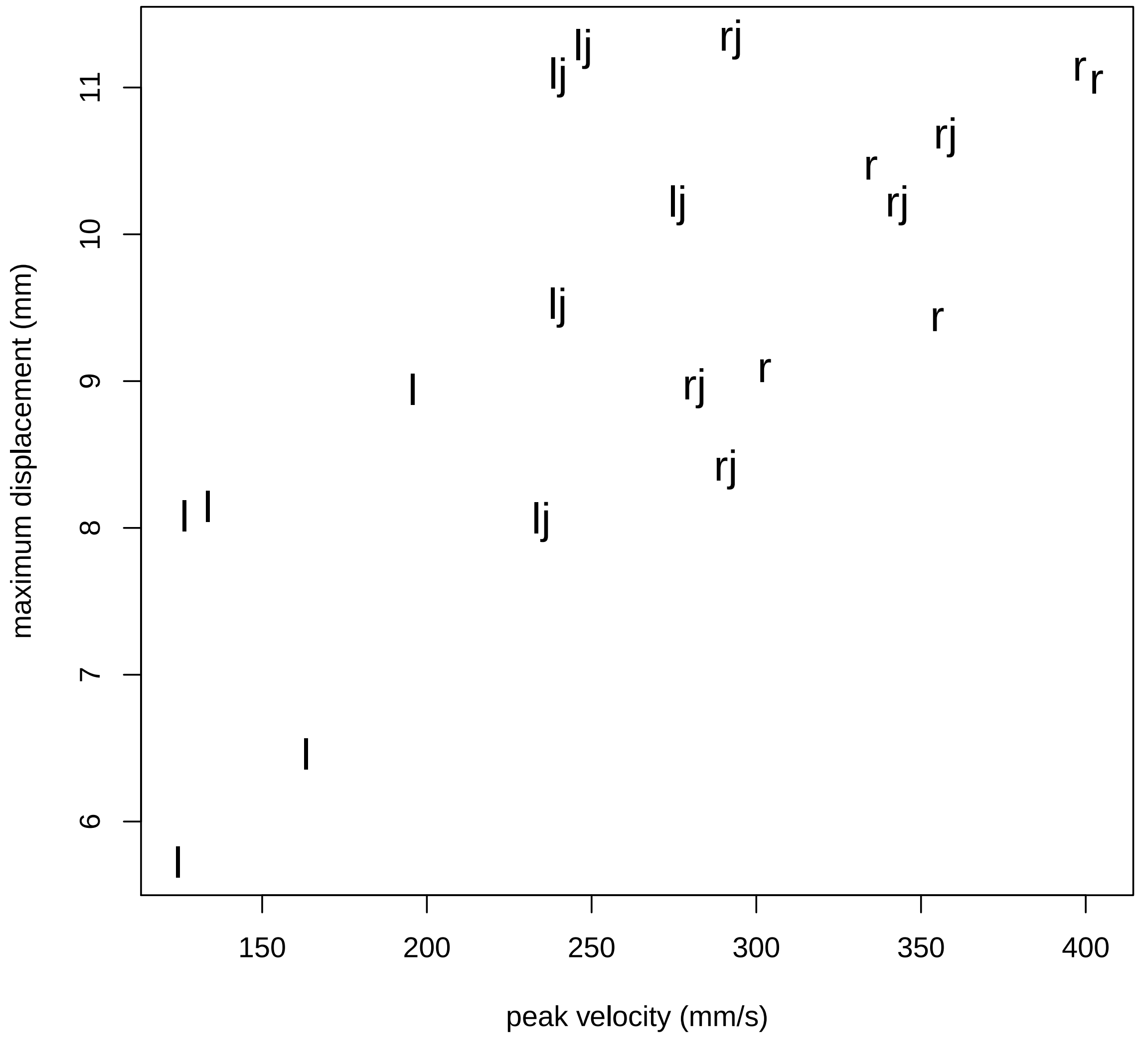


Figure 4.7: Peak velocity dependent on maximum displacement for /l/, /l^j/, /r^j/, and /r/. One token of each consonant per speaker.

are greater in rhotics than in laterals. In addition, the peak velocity is greater in the plain trill as compared to its palatalised counterpart. Although a similar distribution can be observed in stiffness for rhotics, the difference is not statistically significant. The reasons for this are not entirely clear, especially regarding the fact that the tongue tip displacement is similar in both rhotics. In contrast, the tongue tip velocity is significantly smaller in a plain lateral as compared to a palatalised lateral. Although the distance, the tongue tip has to cover from the rest to the target position is generally also greater in /l^j/ than in /l/, the normalisation of the peak velocity through stiffness has no clear pattern.

The Figures 4.8 and 4.9 illustrate that the tongue tip movement from the rest to the target position in palatalised and plain trills is extremely similar (solid vs. dashed lines). The vertical tongue tip position is very similar in both palatalised and plain rhotics, but not in laterals. An additional statistical analysis on the tongue tip vertical and horizontal positions (taken at the maximum constriction point) confirmed this observation: /r^j/ is more fronted than /r/, but the vertical target is the same in both (in line with Kochetov 2005). In contrast, the /l^j/ is more backed as compared to /l/ (vertical position: /r^j/ vs. /r/: $p > 0.1$, /l^j/ vs. /l/: $p < 0.001$; horizontal position: /r^j/ vs. /r/: $p < 0.001$, /l^j/ vs. /l/: $p < 0.001$). This finding might be another piece of evidence for precise articulatory requirements needed for the realisation of alveolar rhotics but seemingly not in laterals.

4.5 Discussion

4.5.1 Summary

The present experiment indicated an overall significant difference in tongue tip peak velocity and stiffness between rhotics and laterals. In line with previous findings (Scobbie et al. 2013, Howson and Kochetov 2015, Hoole et al. 2013) and suggestions (Ladefoged and Maddieson 1996, Recasens and Espinosa 2007), the data demonstrate that alveolar rhotics exhibit a very fast and stiff tongue tip closing gesture. Secondary articulation like palatalisation has an opposite effect on the primary gesture in laterals and rhotics. In palatalised rhotics, the tongue tip presents a lower peak velocity by covering the same distance, compared to plain rhotics. Although the difference in tongue tip stiffness between /r^j/ and /r/ was not significant, there was a tendency for plain rhotics to have also a slightly stiffer tongue tip, at least in some speakers. One of the reasons for a slower tongue tip raising gesture could be the increased tongue tip mass and, consequently, a decreased trilled portion of the tongue tip in a palatalised trill, as compared to its plain counterpart

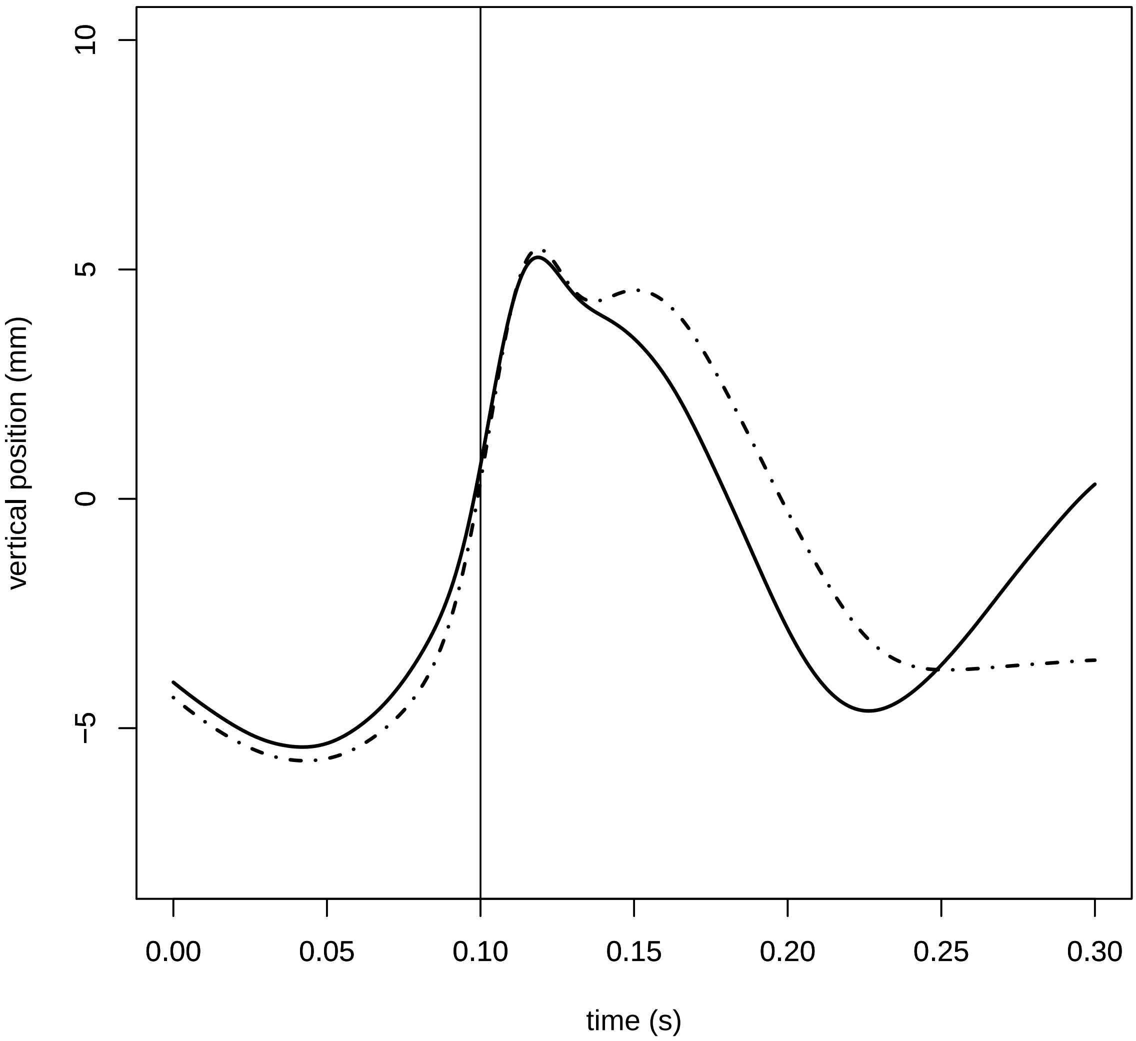


Figure 4.8: Tongue tip vertical position (mm) depending on time (s) in palatalised (solid) and plain (dashed) rhotics. The trajectories are aligned at the point of maximum tongue tip raising velocity (vertical line).

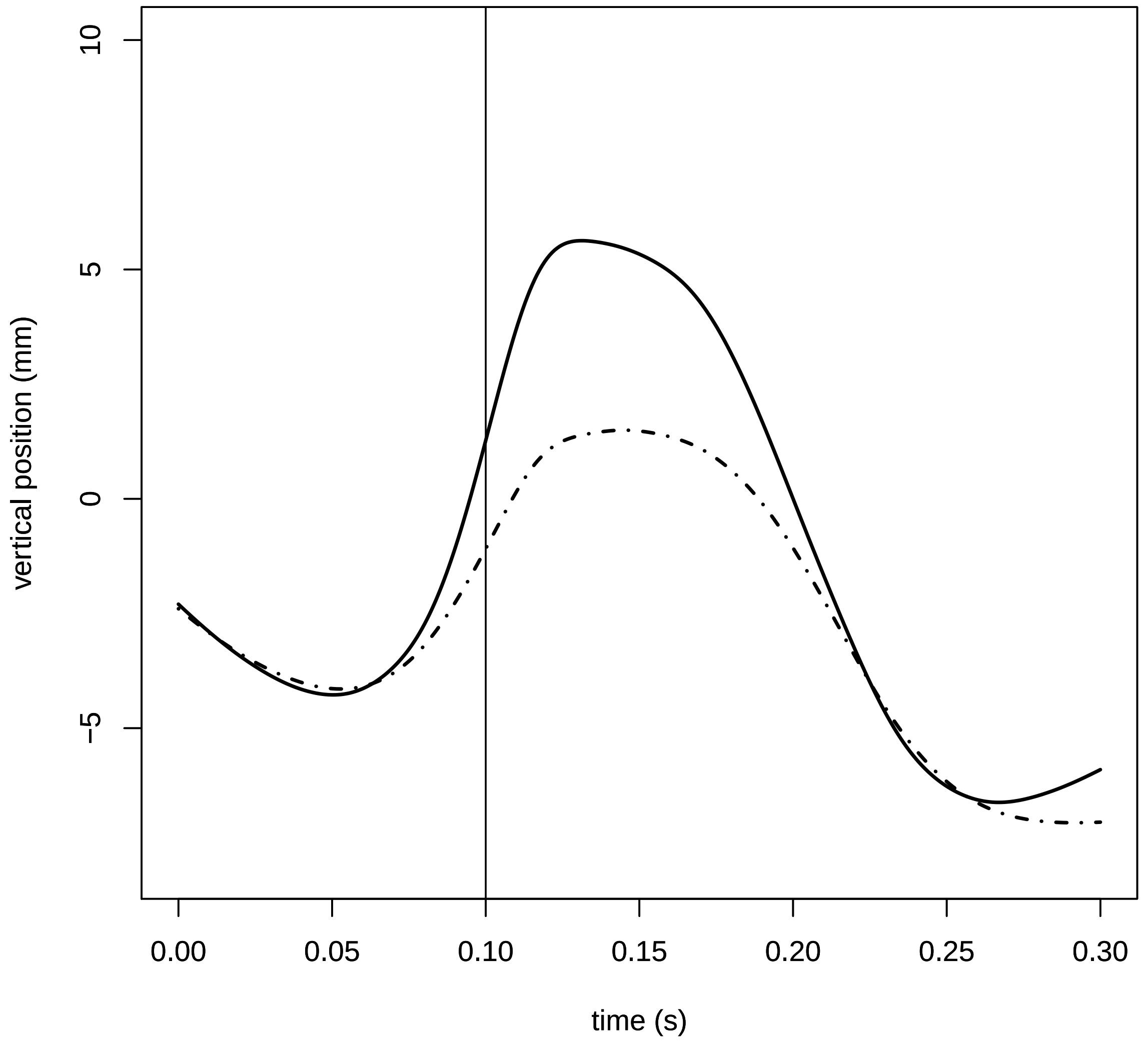


Figure 4.9: Tongue tip vertical position (mm) depending on time (s) in palatalised (solid) and plain (dashed) laterals. The trajectories are aligned at the point of maximum tongue tip raising velocity (vertical line).

(Kavitskaya 1997, Solé 2002: 664).

In contrast, the pattern is not so clear in the case of laterals. In general, the tongue tip presents less maximum displacement and moves more slowly in a plain lateral, as compared to its palatalised counterpart, in most participants. However, the data normalisation through stiffness does not provide a uniform pattern.

If the tongue tip in /r/ has to be very quick for whatever reasons, the velocity will slow down due to some other manoeuvres the tongue has to carry out. On the contrary, the comparatively low tongue tip velocity in plain laterals is likely due to the simultaneous post-dorsum raising and backing necessary for velarisation. The tongue tip in /l/ is so slow as compared to /l^j/ because in the former, the tongue moves in two antagonistic directions: alveolar ridge and velum. In the case of /l^j/, the whole tongue moves in a similar direction: the front of buccal cavity (M.-J. Solé, personal communication, August 2015, Glasgow).

Secondary palatalisation seems to have a different influence on primary gesture in rhotics and laterals. While the tongue tip is "reinforced" by palatalisation in laterals, covering a longer distance with higher velocity in /l^j/ as compared to /l/, it has an opposite effect on rhotics. If the fast tongue tip raising gesture is necessary for trilling, then a slower tongue tip (e.g. due to the presence of secondary gesture) could lead to the cessation of trilling. One of the possible outcomes could be thus the change from a palatalised trill into a trill-fricative as occurred in Czech or Polish. The following discussion will present the relative importance of the fast tongue tip raising gesture for trilling and articulation-based explanations for the change /r^j/ to /r̝/.

4.5.2 Articulatory difference between trills and taps

Before proceeding to the discussion on the relevance of the tongue tip velocity for alveolar rhotics, the articulatory difference between trills [r] and taps [ɾ] should be clarified. It is commonly known that trills and taps are articulated differently. While taps are described as quick single up- and downward movements, trills are produced due to aerodynamic forces: after the tongue tip has taken the critical position near the alveolar ridge, it starts to vibrate due to the Bernoulli effect (McGowan 1992, Solé 2002, Ladefoged and Maddieson 1996: 217-219, 230-231). As Recasens and Pallarès (1999) state "the trill is not a geminate correlate of the tap".

It is also well known, however, that rhotics exhibit many articulatory variations. Even in languages which are described to have a "trill" in their phonemic inventory, these sounds are often realised as taps, fricatives, or approximants (Lindau 1985). The realisation of Russian alveolar rhotics also varies considerably and extends from full trills with several cycles to taps or fricatives/approximants, depending on word domain or speaking conditions (Bolla 1981, Matusevich 1976, Iskarous and Kavitskaya 2010). As Ladefoged and Maddieson (1996: 217) note, "there is a potential conflict between an acoustic definition (more than one period of actual vibration) and an articulatory definition (positioning of the articulators in a configuration such that, given the right aerodynamic conditions, vibration would occur)". It is likely that speakers of Russian plan to produce a full trill. But whether the sound is realised as a trill, a tap or a fricative, is the question of aerodynamic conditions applied a posteriori. In sum, the necessary conditions which should be met at the beginning of the realisation of alveolar rhotics in Russian will be similar. Whether they would lead to the realisation of a full trill or a tap, is another question. On the whole, the high tongue tip velocity has been claimed to be inherent for taps and has been shown to be part of trills in several languages (e.g. Slovak, Czech, Russian; see Hoole et al. 2013, Howson and Kochetov 2015, present Chapter). A more detailed analysis is needed in order to determine whether both trills and taps present the same tongue tip velocity in the closing gesture.

While the articulation of trills and the articulatory difference between trills and taps has been discussed extensively in the past, it is not entirely clear how the closing gesture in trills is performed. The present study confirmed the previous findings that the tongue tip presents a very fast closing gesture not only in taps but also in phonological trills. The reasons for the quick tongue tip gesture in alveolar rhotics are still not entirely clear. Is it a necessary condition for the production of trills?

4.5.3 The importance of tongue tip velocity for the production of trills

Intraoral pressure accumulation

One possible explanation for high tongue tip velocity might be related to the intraoral pressure accumulation: the tongue tip might have to block the mouth cavity quickly and thus enable the rapid intraoral pressure accumulation in trills (necessary for the following mechanical tongue tip vibration due to the Bernoulli effect). Thus, a slower tongue tip movement from the rest position to the vibrating position could cause an insufficient quantity of air to be accumulated in the oral cavity. Moreover, the raised tongue dorsum has as a result a smaller mouth cavity, where less air can be accumulated (Solé 2002). The /r^j/ is produced with excessive intraoral pressure because the quantity of exhaled air is probably the same as by the production of the plain /r/. In sum, a relatively slow tongue tip, which is not able to block the mouth cavity quickly, and high intraoral pressure could cause the cessation of trilling. This way, the pressure is probably too high for the self-sustaining oscillation to be initiated. Instead, the air continues escaping through the tongue tip constriction, which creates an effect of frication.

Tongue tip "critical" position

Alternatively, since "trills involve a highly constrained tongue dorsum and tongue tip to meet the critical positioning required for [...] trilling" (Solé 1998: 413), it can be the case that this critical position has to be met very quickly as well. The present analysis suggests that the tongue tip trajectory is very stable in rhotics, independently of the presence of the secondary gesture, unlike that in laterals (Figures 4.8, 4.9). This finding could be another piece of evidence for the very precise articulatory requirements in trills. It is tentatively hypothesised that the high tongue tip velocity may insure that no undershoot will occur. Undershooting of the tongue tip closing gesture in trills could cause that the air continues to escape through the opening and the trilling fails. In taps, the tongue tip undershoot would lead to an imperfect closure and the realisation of an approximant.

Perception

A quick articulator movement could be important for perception as well. Solé (1998: 414) claims that the acoustic peculiarity of trilling is a "clearly modulated signal, clearly distinct from other speech segments". Abrupt or shorter transitions to and from the consonant could be an additional cue for an alveolar trill, apart from quick change in energy during the close and open phase of a trill[11].

In line with this, the fast tongue tip movement could have consequences for perception. As Ohala (1993: 254) states (developing the idea in Stevens 1980), the listener may prefer fast cues over slow cues like labialisation or velarisation. For Ohala, fast cues are more robust because the listener would need less time to perceive them. Moreover, fast cues would overlap less with neighbouring segments. In trills and taps, the rapid tongue tip movement implies quick formant changes along with a sudden brief interruption in the formant frequencies due to the contact between the tongue tip and alveolar ridge. This

[11] As Hamann (2003: 56) notes "Stevens et al. (1986: 432) point out that an apical movement can be achieved much quicker than a laminal one. Formant transitions of apicals are thus shorter than those of other consonants. Furthermore, the quickness of the apical gesture results in a more abrupt onset for an apical release compared to a laminal release".

makes these consonants very salient. Probably this is one of the reasons why the alveolar trills and taps, although very difficult in their articulation, are so frequent in the languages of the world (Maddieson 1980: 80-82).

4.5.4 Articulation-based theories and sound change

Articulatory Phonology

Contrary to what has been proposed in the earlier versions of Articulatory Phonology (Browman and Goldstein 1990a) and observed in some later studies (Roon et al. 2007), even consonants from the same natural class can be different in stiffness. The findings in the present analysis are in line with previous suggestions in the TADA-modelling (Proctor 2009) that alveolar trills and laterals should present distinct stiffness values reflecting the difference in the tongue tip velocity between them.

The framework of Articulatory Phonology predicts that mainly two processes are responsible for sound change: increased overlap and gestural reduction (Browman and Goldstein 1991). Since the tongue tip and the tongue body are anatomically connected, the overlap between the two tongue body gestures (lowering and backing for trilling vs. raising for palatalisation) impairs the tongue tip gesture and results in reduced peak velocity and stiffness in trills. The impairment of the tongue tip gesture could be one of the negative factors which led to the sound change from a palatalised trill into a trill-fricative in Czech and Polish.

However, it is not clear how and whether stiffness should be integrated into the explanation of sound change in the framework of Articulatory Phonology. Future research should be conducted in order to see whether the change in the tongue velocity might play a role in sound changes, which imply gestural reduction like spirantisation of stops (Beckman et al. 1992) or /ɫ/-vocalisation.

DAC-model

The main point in the DAC-model is the relative resistance of sounds to the influence of phonetic context (Recasens et al. 1997). Although the DAC-model does not handle palatalised consonants in much detail, some conclusions can be drawn from the DAC predictions about the relationship between trills and high front vowels. Alveolar trills and high front vowels present the greatest DAC value, meaning that both types of sounds are highly resistant to coarticulation and, at the same time, exert a big influence on the neighbouring phonetic elements. Recasens (2014: 133) reports that in some Romance languages, alveolar trills changed into alveolar taps when followed by a high front vowel or glide. For Recasens, the reason for this change lies in the articulatory incompatibility between trilling and palatalisation due to the antagonistic constraints imposed on the tongue dorsum, as already reported for palatalised rhotics (Ladefoged and Maddieson 1996, Solé 2002).

Having in mind that palatalised trills present a sequential timing between the two gestures (as reported in Kochetov 2005, Stoll et al. 2015, and in Chapter 3), palatalised trills could also be considered as a cluster consisting of an apical gesture followed by a raised tongue dorsum gesture. Recasens (2014: 165) reports that the tongue tip gesture in the consonants [r], [s] or [ʃ] often changes its constriction location when followed by alveolar or alveolopalatal consonants [t], [n], [l], [ʎ], [ɲ] in a cluster. Especially trills would undergo change because they are articulated with the fast tongue tip movement (as in Spanish from Uruguay or in Sicilian, Recasens 2014: 165).

Recasens reports that trills may be influenced by the following high front vowels leading to the impairment of the tongue tip gesture in the former (Recasens 2014: 133). Interestingly, he finds no examples for the lowering of the /i/-vowel when it is preceded by a trill, although there are many examples of lowering of the front mid vowel /e/ to /a/ (Recasens 2014: 95-102). It can be hypothesised that the high front vowel /i/ is indeed stronger than /r/. In the case of /rʲ/, this would mean that the apical trilling gesture is more likely to be assimilated or blended by the following tongue dorsum raising gesture rather than the reverse. Thus, the DAC-model would correctly predict the change from /rʲ/ into /r̝/ from the articulatory point of view: this change would be due to the negative influence of the tongue dorsum raising gesture on the tongue tip. Whether the impairment in trilling is due to the decreased tongue tip velocity or rather to the sum of several factors remains to be investigated.

4.5.5 Conclusion

It has been found in the present study that the tongue body raising gesture required for palatalisation interferes with the primary gesture in trills, making the tongue tip in /rʲ/ move more slowly, when covering the same distance as in /r/. In contrast, the tongue tip is very slow and covers a smaller distance in /l/ as compared to /lʲ/.

More research is needed in order to investigate whether the tongue tip velocity is important for the production of trills and how the tongue tip and intraoral pressure interact in these sounds. It would be beneficial to analyse whether trills and taps present different tongue tip velocity. Another point of interest is to analyse whether there is a correlation between the failing of trilling and tongue tip peak velocity. However, this is a complicated task with the present technique (EMA) because it is not always clear whether the frication in the acoustic signal is due to the failing of trilling or to the presence of the coils on the tongue tip.

Chapter 5

Conclusion

5.1 General conclusion

The present study was concerned with the question of whether the diachronic instability of a sound can be explained by its synchronic phonetic realisation. As Stevens and Harrington (2014) note, “the link with historical sound change is that synchronic tendencies in the way speech is produced and perceived can, over time, cause permanent categorical change”. In particular, it was intended to clarify why palatalised rhotics, once present in Proto-Slavic, changed in several ways throughout their history in a variety of dialectal outcomes. On the other hand, it has been suggested that rhotics and laterals, although grouped in a common natural class of liquids, present an asymmetrical pattern diachronically (Kochetov 2005). While the opposition between palatalised and plain laterals is relatively stable and still preserved in many modern Slavic languages, the opposition between rhotics was often neutralised. The changes which affected palatalised rhotics produced mainly three outcomes: /r^{j}/ either depalatalised and merged with its plain counterpart /r/, it changed into a sequence of a plain rhotic followed by a palatal glide /rj/, or it became a trill-fricative /r̝/ (Kavitskaya 1997). All three changes brought about the loss of the phonological contrast defined as *palatalised - non palatalised* in the sense of the structuralist framework (Martinet 1952).

The assumption in the present work was that the main reason for the instability of /r^{j}/, and thus for the opposition /r^{j}/-/r/, could lie in the articulation of palatalised rhotics: the tongue dorsum lowering required for trilling is antagonistic to the tongue body raising essential for palatalisation (Ladefoged and Maddieson 1996: 221, Kavitskaya 1997). In order to understand the causes behind the sound changes which affected /r^{j}/, the articulation of palatalised and plain rhotics in modern Russian, which still preserves the opposition /r^j/-/r/, was analysed under different conditions and compared to palatalised and plain laterals.

The present analysis had two goals. It was intended to gain more information about the articulation of palatalised and plain Russian liquids and of palatalised rhotics, in particular. On the one hand, there is still a lack of understanding of the articulation of palatalised consonants (Kochetov's studies on Russian are the most extensive work on this topic published in the last 30 years in the English-speaking literature). On the other hand, there are still not so many articulatory studies on other languages except for English, German, or Spanish. Thus, it is important to provide more information about the articulation of liquids in other languages in order to be able to better understand how they are produced in general. Another objective was to analyse whether the study of the synchronic articulation can shed light on the diachronic processes, which occurred a long time ago. Several works have already shown that the sound change can indeed be imitated in the lab (Ohala 1989, Ohala 1993). Three main chapters of the present thesis thus intended to explain the sound changes which affected palatalised rhotics in Slavic languages, by paying especial attention to their articulation. Thereby, the data were analysed in the frameworks of Articulatory Phonology (Browman and Goldstein 1992), and the DAC-model (Recasens et al. 1997).

Chapters 2, 3, and 4 present the articulatory analysis of palatalised and plain rhotics and laterals in Russian. Each chapter is dedicated to one of the sound changes which affected palatalised rhotics: contrast neutralisation, glide insertion or spirantisation. Chapter 2 investigates the difference between the palatalised and plain consonants of each pair of liquids in different vocalic contexts and word domains and at varying speech rates. It was found that the articulatory difference between palatalised and plain consonants, measured in the tongue dorsum position, is generally smaller in the case of rhotics than that of laterals (confirming the previous findings in Kochetov 2005). The historical survey indicated that the word-final position and the context before high front vowels are the most favourable contexts for contrast neutralisation between /r^j/ and /r/. However, the articulatory difference between /r^j/ and /r/ was not significantly smaller in these contexts as compared to the context before a low vowel /a/, where the contrast is more robust. The tongue dorsum and tongue tip were not significantly reduced in word-final position or at a fast speech rate in /r^j/. These findings suggest that palatalised rhotics, similar to plain ones, imply a very constrained articulation; it seems that at least the articulatory target should be achieved.[1]

[1] But remember that the timing between the tongue tongue and tongue dorsum in /r^j/ showed much

Although the DAC-model has not been extended to palatalised rhotics so far, the present results are in line with this model, which states that rhotics are very constrained sounds (Recasens and Pallarès 1999). However, the DAC-model is not designed for and thus is not able to explain the sound changes like contrast neutralisation or merger. In sum, the articulatory accounts do not provide a sufficient answer for this sound change.

Although not investigated in this study, the perception might play an important role in contrast neutralisation. Both the final position and the position before front vowels are dangerous for palatalised consonants, especially when the tongue dorsum raising is delayed as in the case of palatalised rhotics (see Chapter 3 for more details). As Kochetov (2005) suggests, the palatalisation can be perceived only by VC-transitions word-finally, while it can be identified intervocalically at both CV- and VC-transitions. It has often been stated that the CV-transitions are more salient in the case of palatalised consonants than the VC-transitions (Kochetov 1999). The acoustic cues of coda /r^j/ might be even less salient as compared to coda /l^j/ because of the delayed tongue dorsum in the former. In addition, the alveolar rhotics usually have a shorter acoustic duration than laterals. Thus, the palatalisation might still be perceived in the lateral itself, but less so in the rhotic.

The context of high front vowels is hazardous for all palatalised consonants equally (Padgett 2003, Ohala 1994). The listener may be unsure as to whether a consonant in this context is phonologically palatalised or whether the higher F2 is just due to the coarticulation with the following vowel. However, since the articulatory difference is smaller between trills than between laterals, the presence or absence of palatalisation may already be perceived in the lateral itself, unlike in the trill (because of its shorter acoustic duration).[2] Thus, the contrast between /r^j/ and /r/ is perceptually less stable in the context of high vowels, although the distance between the tongue dorsum positions is the same in all vocalic contexts in rhotics.

Chapter 3 investigated the timing between the tongue tip and the tongue dorsum raising in palatalised rhotics and laterals in different word domains. The labelling permitted a reliable analysis of consonants only in the /a/-context. The data showed that the timing between the two gestures is sequential in palatalised rhotics, presenting a delayed tongue dorsum in all word positions. Moreover, the timing is also quite unstable in rhotics: it varies due to the influence of word position and speech rate. Laterals, however, present a relatively stable and almost simultaneous timing between the tongue tip and the tongue

intra-speaker variation.

[2] Usually, high F2 transitions in the flanked vowels are the main acoustic cue for palatalisation (Bondarko 1998).

dorsum.

Palatalised liquids in Russian do not fit well in the framework of AP (Browman and Goldstein 1995) and Sproat and Fujimura (1993), which mainly analysed English liquids. More studies on phonemically palatalised consonants are necessary in order to understand whether the observed timing and the difference between rhotics and laterals are language-specific or are inherent to the articulation of these consonants. In particular, it can by hypothesised that the timing between the two gestures should be simultaneous in a phonemically palatalised consonant (also in order to differentiate them from the sequences consonant followed by jod). If so, palatalised laterals would satisfy this assumption (see further evidence in Gick et al. 2006 and Kochetov 2005). Palatalised rhotics, however, present an exception because of their particular articulation and thus are virtually not able to be realised with the simultaneous timing between the two gestures.

Another remarkable finding was to discover that the delayed tongue dorsum in /r^j/ overlaps with the following vowel without affecting the acoustic duration of the CV-sequence. This finding is in line with the assumption that the tongue dorsum is a vocalic gesture (Sproat and Fujimura 1993, Browman and Goldstein 1995), although it is inherent to the production of palatalised consonants.

As far as the sound change is concerned, the AP provides a partly satisfying explanation for the sound change from /r^j/ to /rj/. The AP predicts that the glide insertion would take place due to the sequential timing (Browman and Goldstein 1991, Beckman et al. 1992), which is the case in /r^j/. The DAC-model and Ohala express the same opinion (Recasens 2014, Ohala 1974). However, it is not clear which role the speech rate would play in this sound change, according to AP. While /r^j/ presents a relatively big lag at a slower speech rate in initial position, it is considerably reduced at a faster speech rate. But since it is still sequential, the sound change can take place. Recasens (2014: 28) also states that the glide insertion is due to the sequential timing in palatalised consonants. Moreover, he claims that the F2 values also play a considerable role (Recasens and Espinosa 2010). The present analysis showed that the F2 was indeed higher in the transitions from /r^j/ into the following low vowel, as compared to the /l^ja-/-sequence.

Finally, Chapter 4 analysed the influence of the palatalisation on the tongue tip in Russian liquids. The sound change which took place in Czech and Polish (/r^j/ into /r̝/) suggests that the tongue tip might be negatively influenced by the palatalisation. Here, the tongue tip peak velocity, maximum displacement, and stiffness in palatalised and plain consonants in word-initial position were analysed. The results confirmed the previous findings that trills present a much faster tongue tip closing gesture compared to laterals (Hoole et al. 2013, Pouplier and Beňuš 2011, Howson and Kochetov 2015). It was then hypothesised that a quick tongue tip closing movement might be important for the production of trills, either for the intraoral air pressure accumulation, for taking the "critical" tongue tip position, or for perception reasons. It has been demonstrated here that the tongue tip velocity, and probably also stiffness, are impaired in /r^j/ as compared to /r/. Contrary to this, the tongue is even faster and covers a larger distance in /l^j/ compared to /l/. The findings suggest that the tongue tip in trills is indeed negatively influenced by palatalisation: it moves more slowly, although it covers the same distance and has to occupy the same vertical position as in the case of /r/.

Due to the fact that EMA is quite a complex and expensive technique, relatively few studies have analysed the tongue tip velocity in consonants so far (although see Scobbie et al. 2013 for the analysis of the peak velocity by means of ultrasound). In addition, the investigations conducted in the 80s of the 20th century (see Gay 1981, Kent and Moll 1972, Kelso et al. 1985, Ostry and Munhall 1985) showed that there is much variation in the peak velocity depending on the phonetic context. As a consequence, the articulatory velocity and stiffness are not so often incorporated into the theories of speech production. Although the framework of AP integrates stiffness into its modelling, not so many studies concerning this topic have been conducted so far. The AP suggested that stiffness may differentiate natural classes of sounds (Browman and Goldstein 1992). The present analysis shows that stiffness can vary even in a natural class of liquids. Otherwise, it can be hypothesised that alveolar trills present an overall exception and require special articulatory conditions, e.g. a very fast tongue tip closing gesture. Although the DAC-model does not operate with the tongue velocity, it correctly predicts that the tongue dorsum should have more influence on the tongue tip in /r^j/ than the reverse (Recasens 2014: 165).

The present study is the first extensive work which is dedicated to analysing the articulation of palatalised rhotics under varying phonetic conditions. Although it has often been claimed that the reason for their diachronic instability lies in the articulation, only a few studies have analysed palatalised rhotics broadly so far (Kavitskaya 1997, Kavitskaya et al. 2009, Kochetov 2005, Iskarous and Kavitskaya 2010, Proctor 2009). The present study further provides an articulatory analysis of plain rhotics and palatalised and plain laterals, which have been subject to numerous studies in other languages. The comparison of Russian liquids with the data gained from other languages should expand our understanding of how this class of sounds is produced. Liquids are very common in the languages of the world; at the same time, they can be quite difficult to master.[3] Thus, to understand how liquids are articulated cross-linguistically can help us to understand how they should be correctly produced, as well as how their articulation can be improved in children and adults with pronunciation problems.

Another important point on which this work focused was that the reasons for the diachronic sound change can be found in the articulation of a given sound, especially in cases when this sound change took place in several languages. Thus, sequential and unstable timing between the tongue tip and tongue dorsum gestures, comparatively small articulatory difference between palatalised and plain rhotics or the negative influence of the palatalisation gesture on the tongue tip have been claimed here to be responsible for the sound changes which affected /r^j/ in Slavic languages.

The present work also analysed the articulatory data in light of the AP framework (Browman and Goldstein 1992) and the DAC-model (Recasens et al. 1997). It extends these theories on new data - the phonemic distinction between palatalised and plain consonants - and provides new insights and suggests some limitations of these accounts.

5.2 Limitations of the present study

The present study also presents several limitations. First of all, the articulatory experiment was based on speech recorded in the lab, which has often been claimed to provide critical data. The participants were supposed to speak freely under very unnatural conditions: enclosed in a small cubicle, with coils attached to their tongues. The task they had to perform was to repeat somewhat meaningless phrases several times. Although such a small number of participants (six) is typical for EMA experiments, which require extensive and time-consuming posterior labelling and data evaluation, it could give a distorted picture of the phenomenon. It is also doubtful whether the fast speech rate achieved the goal of eliciting hypoarticulated speech. Although the statistical analysis showed a significant difference in duration between the two speech tempo conditions, it was sometimes difficult to say whether the speech was indeed hypoarticulated. Some participants still pronounced everything well. Very fine grained data could nevertheless be elicited in this experiment, which provided new insights.

[3] See the project on liquids *Solving the puzzle of complex speech sounds* currently carried out by Michael Proctor. More information on http://mproctor.net/research.html. Last accessed on 2016-09-27.

5.3 Recommendations for future research

In the future, more participants with an extensive set of data should be analysed. Several studies have shown that the token frequency can play an important role in sound change, where more common words can present a greater reduction (Bybee 2002). Here, word frequency was not taken into consideration, because attention was paid to the very controlled phonetic context instead. In addition, the inter-speaker variation could be analysed in more detail in the future. Here, the data were usually averaged (but more inter-speaker analysis in Chapter 4), although there is a growing evidence that speakers may differ in their behaviour with respect to the sound change initiation and propagation (see Stevens and Harrington 2014).

It would be also very beneficial to provide a broader and more uniform study of other Russian palatalised consonants, because the studies which have been done so far usually treat only a few sets of consonants with little contextual variation. In addition, a cross-linguistic comparison of the articulation of palatalised and plain liquids would be very valuable (see previous work in Gick et al. 2006, Recasens 2012a). Russian is the most analysed language from the Slavic family and still, there is a lack of understanding about how its sounds are produced and what the exact difference to other languages actually is (see Öhman 1966). The articulation of palatalised consonants in other Slavic languages should also be analysed in more detail.

A more detailed further analysis of the acoustics and especially of the perception of palatalised liquids is necessary in order to determine whether the articulatory differences between rhotics and laterals are reflected or not in the perception. For example, an experiment could be carried out by creating continua between /rj, r/ and /lj, l/ in order to determine whether e.g. there is a greater bias towards perceiving /r/ vs. /rj/ (compared with /l/ vs lj/) especially in final position. In addition, it would be very beneficial to analyse the difference in airflow between palatalised and plain rhotics in line with the studies of plain trills conducted by Solé (1998, 2002). Solé demonstrated that the correct quantity of intraoral air pressure is essential for the production of trills. If the same or even a greater quantity of air is exhaled by the production of /r^j/ as compared to /r/, but the intraoral cavity is smaller in the former than in the latter, this could be another reason for the cessation of trilling.

It remains to be investigated whether the velocity of the articulators is important for the production of trills, and whether there is a difference between trills and taps. Would a slower tongue tip in a planned trill lead to the production of a tap or an approximant instead? More research is needed in order to see whether and which role the fast tongue tip closing gesture plays in the production of trilling.

What should also be investigated is how secondary articulation like palatalisation or velarisation could be incorporated into the framework of Articulatory Phonology, apart from other factors like perceptual recoverability (Kochetov 2005, Chitoran et al. 2002, Gick et al. 2006). What should also be analysed is how articulator velocity and stiffness can be integrated more tightly into the AP and probably into the DAC-model. A more general question concerns the relative role of the stiffness for sound change. Is a greater stiffness necessarily better than a lower stiffness or the reverse? Does it depend on the consonant or articulator involved? Can greater stiffness lead to a faster deterioration of a sound, especially in consonants produced with the tongue tip? Or is a smaller stiffness and slower tongue velocity of the articulator preferable because it assures the target achievement? Should the tongue be quick instead in order not to be overlapped with other sounds? In general, the analysis of the articulator velocity is a very interesting and promising, although difficult task which requires much data and design control.

The present analysis tentatively suggests that the tongue dorsum is stronger than the tongue tip in Russian /rʲ/. What could probably be modelled in the lab is whether the change, that Russian could hypothetically undergo in the future, would be the Czech and Polish way, i.e. the change from a palatalised /rʲ/ to a trill-fricative /r̝/. Would the situation be similar in other Slavic languages which still preserve palatalised rhotics?

In sum, the present thesis has shown that the diachronic instability of palatalised rhotics can be observed in their synchronic articulation. The main reasons found here are a small articulatory difference between /rʲ/ and /r/, a sequential and unstable timing between the tongue tip and tongue dorsum, and impaired tongue tip, observed in a slower tongue tip closing gesture. The data also suggest that even palatalised rhotics present quite a constrained articulation, compared to laterals, especially as far as the tongue tip and tongue dorsum targets are concerned.

Appendix A

word position	target word	translation
initial	ramka	'frame'
	r^{j}abchik	'grouse'
	rɨba	'fish'
	r^{j}imskij	'Roman'
	rupor	'mouthpiece'
	r^{j}umka	'glass'
	lampa	'lamp'
	l^{j}amka	'strap'
	lɨsɨj	'bald'
	l^{j}iza	name
	lupa	'magnifier'
	l^{j}uba	name
medial	parad	'parade'
	zar^{j}ad	'charge'
	porɨv	'gust'
	gor^{j}im	'(we are) burning'
	oru	'(I am) shouting'
	var^{j}u	'(I am) cooking'
	salat	'salad'
	pal^{j}at	'(they are) firing'
	kalɨm	'dowry'
	nal^{j}im	'burbot'
	valun	'boulder'
	sal^{j}ut	'firework'
final	komar	'mosquito'
	janvar^{j}	'January'
	sɨr	'cheese'
	puzɨr^{j}	'bubble'
	tur	'tour'
	glazur^{j}	'glaze'
	slomal	'(he) broke'
	emal^{j}	'enamel'
	pomɨl	'(he) washed'
	kavɨl^{j}	'feather grass'
	nadul	'(he) pumped up'
	nul^{j}	'zero'

Table 5.1: Speech material, main study

Appendix B

Previous works

Stoll, T., Harrington, J., and Hoole, P. (2015). Intergestural organization and CV-overlap in palatalized liquids in Russian. In *Proccedings of the 18th International Congress of Phonetic Sciences*, Glasgow, UK.

Stoll, T., Hoole, P., and Harrington, J. (2015). Influence of palatalisation on tongue tip velocity in trills and laterals. *15th Conference on Laboratory Phonology.* Peer-reviewed abstract.

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