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HELEN TÜRK

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Institute of Estonian and General Linguistics, Faculty of Arts and Humanities, University of Tartu, Estonia

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CONTENTS

LIST OF PUBLICATIONS

[P1] Türk, Helen; Lippus, Pärtel; Šimko, Juraj 2017. Context-dependent articulation of consonant gemination in Estonian. – Laboratory Phonology: Journal of the Association for Laboratory Phonology, 8 (1), 1–26. http://doi.org/10.5334/labphon.117.

[P2] Türk, Helen 2018. The Three-Way Distinction of Consonant Duration in Estonian. – Proceedings of the 9th International Conference on Speech Prosody. Katarzyna Klessa, Jolanta Bachan, Agnieszka Wagner, Maciej Karpiński, Daniel Śledziński (Eds.), 656–660. dx.doi.org/10.21437/SpeechProsody.2018–133.

[P3] Türk, Helen 2019. Interactions between segmental context and quantity: temporal patterns of geminates in Estonian. – Linguistica Uralica, LV (4), 241–260. https://dx.doi.org/10.3176/lu.2019.4.01.

[P4] Türk, Helen; Lippus, Pärtel; Pajusalu, Karl; Teras, Pire 2019. The acoustic correlates of quantity in Inari Saami. – Journal of Phonetics, 72, 35–51. doi.org/10.1016/j.wocn.2018.11.001.

1. INTRODUCTION

1.1. Objectives

A three-way consonantal quantity distinction exists in the phonology of a handful of languages and can determine the difference between word meanings or word forms. It is more common for languages to have binary consonantal quantity systems with short and long length categories; for example, Finnish (Suomi, Toivanen, Ylitalo 2008), Hungarian (Neuberger 2015), Italian (Payne 2005), Japanese (Idemaru, Guion 2008) and Libyan Arabic (Issa 2015). Long consonants are generally referred to as geminate consonants. Ternary consonantal quantity systems are quite rare, and have been found in Finno-Ugric languages, such as Estonian (Lehiste 2003), Livonian (Lehiste et al. 2008) and several Saami languages – Inari Saami (Bye, Sagulin, Toivonen 2009), North Saami (Magga 1984), and Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014). In these languages, consonants could be described as short (referred to as Q1), long (Q2) and overlong (Q3). Long and overlong length categories in some languages are also called half-long and long geminates or short and long geminates.

The current thesis is an experimental-phonetic study that investigates the phonetic properties of the three-way consonantal quantity systems in two Finno-Ugric languages: Estonian and Inari Saami. Estonian is a language with a complex quantity system involving a ternary distinction for both vowels and consonants, while Inari Saami has a ternary distinction for consonants and a binary distinction for vowels. In both languages, geminates are defined as consonants on the boundary of stressed and unstressed syllables of a disyllabic foot. In Estonian, quantity has been described in terms of the duration ratios of these syllables. This has been considered the best way to describe quantity; however, test material focusing on vocalic quantity has mainly been used. For feet with geminates it is not exactly known where the syllable boundary within a geminate consonant is located. That could be one reason why, relative to vocalic quantity, the characteristics of consonantal quantity have been given undeservedly little attention in previous studies on Estonian quantity (Eek 1974; Lehiste 1966; Suomi et al. 2013). Regarding the three-way consonantal quantity distinction in Inari Saami, only a few phonetic studies can be found, and these deal with temporal aspects of quantity (Bye, Sagulin, Toivonen 2009; Markus et al. 2013). There continues to be uncertainty concerning how quantity is realized in words with different foot structures and to what extent non-temporal aspects play a role.

There are two primary aims of this thesis: a) to investigate what the phonetic characteristics are that describe the three-way consonantal quantity distinction in Estonian and Inari Saami; b) to ascertain to what extent quantity interacts with segmental context, i.e., to what extent there are interactions between prosody (quantity) and microprosody (segmental context).

The first aim is motivated by the need for describing the three-way consonantal quantity contrast more systematically in order to better understand its

phonetic nature and to establish the differences and similarities cross-linguistically. For this, Estonian and Inari Saami form a good set of languages as they belong to different branches of Finno-Ugric languages (Finnic and Saamic, respectively). As mentioned above, consonantal quantity in Estonian has not been studied in great detail and there are only a few studies concerning quantity in Inari Saami. The current doctoral thesis aims at coming a step closer towards filling this gap from a phonetic point of view. More precisely, the first part of the thesis asks: a) what are the articulatory properties of the Estonian consonantal quantity system and whether the three-way nature of the quantity system is also reflected in the articulatory movements; b) how is the Estonian consonantal quantity distinction realized acoustically: what are the temporal characteristics of geminates, and are there correlations between neighboring segments; c) how is three-way consonantal quantity manifested acoustically in Inari Saami disyllabic feet with different structures; d) how do neighboring segments influence each other in Inari Saami disyllabic feet; e) what is the role of fundamental frequency and intensity characteristics in terms of quantity in Inari Saami?

The second aim is motivated by the fact that in most studies, quantity has been investigated using test material where segmental context does not vary or variation has been neglected. This doctoral dissertation gives more insight into how three-way consonantal quantity is realized when the underlying segmental context varies. This is studied from the articulatory and acoustic point of view in terms of quantity in Estonian by investigating: a) whether and how segmental context affects quantity realization on the articulatory level; b) how quantity is acoustically manifested for consonants with different place and manner of articulation; c) to what extent acoustic quantity characteristics interact with consonantal and vocalic context.

1.2. Structure of the dissertation

The thesis is divided into two parts – the introduction and a collection of publications. The introductory part consists of six chapters. The first chapter provides a general introduction to the topic of the thesis along with the main research questions and provides an overview of the publications and author's contributions in the co-authored publications. Chapter 2 introduces the data and methods used in the thesis. In Chapter 3, general terms connected to the topic of the thesis are explained, followed by an exploration into the phonetic properties of geminates in different languages with binary consonantal quantity systems as well as by a description of the properties of three-way consonantal quantity in Estonian and Inari Saami. Chapter 4 summarizes and discusses the results of the four publications. The main conclusions of the thesis and perspectives for future research are presented in Chapter 5. Finally, Chapter 6 provides a summary in Estonian. This is followed by all of the references cited in the introductory part. The second part of this dissertation consists of the four publications.

1.3. Overview of publications and author's contributions

The four publications in part two of this thesis explore different aspects of the three-way consonantal quantity contrast in Estonian and Inari Saami. Publications [P1], [P2] and [P3] deal with consonantal quantity in Estonian, while quantity in Inari Saami is studied in publication [P4]. Below, an overview of the main topics considered in each publication and descriptions of authors' contributions for the co-authored papers [P1] and [P4] are given. The co-authors have seen the descriptions and concur on them.

Publication [P1] investigates the articulatory properties of three-way consonantal quantity in Estonian. The main issue in this article is whether and how the three-way nature of Estonian quantity is reflected in the articulatory movements and to what extent quantity interacts with segmental context. Pärtel Lippus and Juraj Šimko collected the test material, Helen Türk and Pärtel Lippus did the acoustic annotation and segmenting of the recordings. Post-processing of the articulatory data was done by Šimko, and Türk did the articulatory labeling. The main parts of the paper were written by Türk, while consulting with the second and third author, who commented on and corrected drafts of the paper. Šimko wrote the summary on the articulation of geminates in section 1.1., contributed to writing section 1.4., wrote most of section 2, and three last paragraphs of the discussion. Statistical data analysis and figures were done by Lippus and Šimko.

Publication [P2] is an acoustic-phonetic study that deals with the durational properties of the Estonian three-way consonantal quantity contrast considering the quality of the intervocalic consonants. The durations and duration ratios of different consonants in the three quantity degrees are analyzed and compared to the results of Arvo Eek (1974), thus offering an account for consonantal quantity characteristics in spontaneous Estonian, and supplementing the results of the older study, which used read speech.

Publication [P3] extends the analysis of publication [P2] and investigates the durational properties of Estonian consonantal quantity in terms of the quality of different intervocalic consonants and surrounding vowels. The main focus of this paper is to show the general trends in the interactions between quantity, consonantal contexts and vocalic contexts.

Publication [P4] deals with the acoustic correlates of three-way consonantal quantity in Inari Saami. The main questions are how ternary consonantal quantity is realized in different foot structures, how neighboring segments correlate with each other, and what the roles of fundamental frequency and intensity are in quantity manifestations. Pire Teras compiled the test sentences and the data was recorded by Pire Teras and Karl Pajusalu. Teras and Türk segmented and annotated the data. The paper was written by Türk while consulting the other authors, who commented on drafts of the paper. Lippus wrote the code for extracting the data from the annotated wave files and generating the figures. Statistical analyses were done by Türk.

2. DATA AND METHODS

In this chapter, the materials and methods used in the four publications are presented. Section 2.1. introduces the articulatory data used in article [P1], section 2.2. gives an overview of the acoustic data used in publications [P2] and [P3], followed by the description of the acoustic data of publication [P4] in section 2.3.

2.1. Articulatory material from Estonian

Articulatory data in publication [P1] was recorded from four Estonian test subjects (2 males and 2 females aged 34–57 years). The recordings were carried out at the University of Helsinki using an electromagnetic articulograph (EMA) AG500 from Carstens Medizinelektronik. EMA sensors were placed on the middle portion of each test subject's tongue, above and below the vermilion border of the lips, and below the lower incisors. Articulatory signals from the tongue, lips (upper and lower lip) and jaw were recorded in parallel to the acoustic signal.

The subjects were asked to read a test word from the computer screen and repeat it approximately ten times in a row without pauses between repetitions. The test words are presented in Table 1.

Table 1. Stimuli with possible quantity combinations.

Q1	**Q2**			**Q3**		
	C2	V1	V1C2	C2	V1	V1C2
pɑpi	pɑp:i*	pɑ:pi	pɑ:p:i	pɑp::i*	pɑ::pi	pɑ:p::i
pipɑ	pip:ɑ	pi:pɑ	pi:p:ɑ	pip::ɑ	pi::pɑ	pi:p::ɑ
tɑpi	tɑp:i*	tɑ:pi	tɑ:p:i	tɑp::i*	tɑ::pi	tɑ:p::i
tipɑ*	tip:ɑ*	ti:pɑ	ti:p:ɑ	tip::ɑ	ti::pɑ*	ti:p::ɑ

** marks meaningful words in Estonian.*

Test stimuli were disyllabic CVpV-words that comprised all seven possible Estonian quantity combinations. The word-initial consonant was /p/ or /t/, the vocalic context was /ɑ-i/ or /i-ɑ/, and the intervocalic consonant was /p/; this resulted in 28 stimuli. For each stimulus, between 118 and 129 tokens were collected. All of the tokens were segmented and labeled using Praat (Boersma, Weenink 2014) and articulatory labeling was done in MATLAB.

2.2. Acoustic material

In publications [P2], [P3] and [P4], test material came from acoustic recordings: publications [P2] and [P3] used data from Estonian spontaneous speech and [P4] from read speech in Inari Saami. Section 2.2.1. describes the acoustic data for Estonian and section 2.2.2. gives an overview of the test material for Inari Saami.

2.2.1. Estonian test material

The data in publications [P2] and [P3] were collected from the University of Tartu Phonetic Corpus of Estonian Spontaneous Speech (Lippus et al. 2006). The data for the study was collected in March 2017 using the recordings from 2006–2017. At that point the total duration of segmented recordings in the corpus was 79 hours. Data relevant for the study was found from 74 speakers. This consisted of 40 male and 34 female speakers (aged 20–85 years; with an average age of 37.8 years for males and 37.1 years for females), all of whom speak Standard Estonian.

Table 2 presents examples for the test words used for the analysis. The data comprised of phrase-medial disyllabic words with short first syllable vowels (V1), second syllable vowels (V2) and intervocalic consonants (C2) with varying length. In total, 1855 words were extracted.

Table 2. Examples of the test words in three quantity degrees.

Structure	Obstruents	Sonorants
Q1 CVCV	saba /sɑpɑ/ ‘tail, nom.sg’	kala /kɑlɑ/ ‘fish, nom.sg’
Q2 CVCCV	kapi /kɑppi/ ‘cupboard, nom.sg’	valla /vɑllɑ/ ‘borough, gen.sg’
Q3 CVC:CV	kappi /kɑp:pi/ ‘cupboard, part.sg’	panna /pɑn:nɑ/ ‘to put’

The intervocalic consonants were /p, t, k, s, m, n, l/ and the surrounding vowels were phonologically short monophthongs /i, y, u, e, ø, ɤ, o, ɑ/ (missing /æ/) in V1 position and all five possible monophthongs /i, u, e, o, ɑ/ in V2 position. The duration of each segment was extracted with a Praat script from the annotated TextGrids.

2.2.2. Inari Saami test material

The data in publication [P4] were recorded in 2013 from four male native speakers of Inari Saami, aged 62, 68, 76 and 77 years (average age 70.8). Two speakers were born in Inari, one in Syysjärvi and one in Ylivieska. The speakers were all bilingual in Inari Saami and Finnish. They were given a sheet of paper

with test sentences containing test words with intervocalic consonants in the three quantity degrees and asked to read these aloud. Examples of the test words are presented in Table 3. The test words had six different foot structures: CVCV, CVCCV, CVC:CV(C), CVVCV(C), CVVCCV(C), CVVC:CVC. The test words occurred in phrase-medial and phrase-final position of the sentences and were disyllabic with short intervocalic consonants (Q1), half-long (Q2) or long (Q3) geminates or consonant clusters. The vowel in the first syllable was a phonologically short or long monophthong or a diphthong, and the vowel in the second syllable was phonologically short.

Table 3. Six different foot structures and examples with monophthongs and diphthongs in the first syllable (S1).

Foot structure	S1 monophthong	S1 diphthong
CVCV	*sare* /sɑre/ 'blueberry, acc./gen.sg'	*kye'le* /kyele/ 'fish, acc./gen.sg'
CVCCV	*saṛe* /sɑrre/ 'blueberry, nom.sg'	–
CVC:CV(C)	*pállu* /pæl:lu/ 'ball, nom.sg'	*uáb'bi* /uæb:bi/ 'sister, nom.sg'
CVVCV(C)	*määli* /mææli/ 'soup, acc./gen.sg'	*muorâ* /muorɤ/ 'tree, acc./gen.sg'
CVVCCV(C)	*määḷi* /mæælli/ 'soup, nom.sg'	*muoṛâ* /muorrɤ/ 'tree, nom.sg'
CVVC:CVC	*määllid* /mææl:lid/ 'soup, part.sg'	*muorrâd* /muor:rɤd/ 'tree, part.sg'

For the analysis, the durations of all segments were measured in milliseconds, and the fundamental frequency values were measured in Hertz at 20 equally distributed points from the beginning of V1 to the end of V2. The mean intensity values in decibels were measured for vowels and the intervocalic sonorant consonants. In total, 1463 words were used for the analysis of duration, 1043 for fundamental frequency and 597 for intensity.

2.3. Statistical analyses

Statistical analyses in all publications were carried out using the software R (R Development Core Team 2014). For the statistical analyses in publications [P1], [P2] and [P4], the main effects of independent variables and their interactions on the dependent variables were described using linear mixed-effect (also called hierarchical or multilevel) models with the lme4 package (Baayen, Davidson, Bates 2008; Bates et al. 2014) and Tukey HSD pairwise comparison for post-hoc testing. Mixed-effect models have fixed effects as model parameters that do not vary for a population, and random effects as model parameters that vary for a population. In the models for all three publications, variation was considered for speakers and test words.

In publication [P1], mixed-effect models were used in order to evaluate whether and to what extent articulatory characteristics are affected by quantity

and variation in segmental context. Therefore, for each dependent variable (i.e., articulatory feature) the models were run with the same set of fixed factors. Statistical significance was tested for pairwise individual contrasts by using a multiple comparison technique.

In publications [P2] and [P4], mixed-effect models were implemented for evaluating the presence or absence of the explanatory factors in the quantity manifestations by running the models in an incremental fashion, i.e., the effects of fixed factors and their interactions were added to the models and tested one by one for their statistical significance. The aim of the mixed-effect modeling in publication [P2] was to estimate whether and how the intrinsic properties of the intervocalic consonants explain variation in the temporal realization of consonantal quantity in Estonian. In publication [P4], the significance of the main effects of quantity and phrasal position as well as their interactions were tested on the segmental durations, and on F0 and intensity measurements in Inari Saami.

In publication [P3], Bayesian generalized mixed-effect modeling was used by implementing the brms package (Bürkner 2017) via Stan (Stan Development Team 2017a). The Bayesian approach to statistics was chosen in order to better interpret complex relationships between different variables in interactions and deal with smaller sample size in hierarchical models. In Bayesian inference, there are no p-values like in traditional inference. Thus, it is not based on statistical significance and is more intuitive. This approach to modeling enables one to flexibly fit more complex models, better deal with smaller sample sizes, add prior knowledge to the models (with this, scientific hypotheses can be included in the analysis) and get more information about an effect by providing a probability distribution of plausible values (Vasishth et al. 2018).

This kind of approach to statistics was considered beneficial for the aim of publication [P3]: to assess variation in the duration of the intervocalic consonant in terms of a three-way interaction between quantity, place and manner of the intervocalic consonant and the vocalic height of V1 and V2. Similar to traditional mixed-effect models, the Bayesian models used in article [P3] also took variation for speakers and test words into account. As the Bayesian approach to statistics does not largely depend on sample size (as opposed to traditional statistics), it was found advantageous for the data collected from spontaneous speech, where the number of tokens for each category could not be fully controlled for. In addition, it made it possible to interpret the results straightforwardly by providing marginal effects plots that showed the posterior means with 95% credible intervals for consonant durations under different conditions.

3. THEORETICAL BACKGROUND

This chapter explores the key terms used in this thesis and presents the main characteristics of geminate consonants in different languages. The term *prosody* will be briefly explained first, as the main topic of this thesis deals with the phonetic characteristics of the three-way consonantal quantity, which is considered to be a prosodic phenomenon. The second aim of the thesis involves studying interactions between segmental context and quantity, which makes it relevant to clarify the meaning of *microprosody*.

Section 3.2. gives an overview of the phonetics of geminate consonants in binary and ternary systems. Previous research on quantity in Estonian and Inari Saami is discussed in section 3.3.

3.1. Prosody and microprosody

The term *prosody* includes phenomena that are realized on speech units larger than just a single segment, such as a syllable, foot, word, phrase or utterance. Prosodic phenomena include length, stress, tone, rhythm and accent. It has been claimed that prosodic features are independent of speech mechanics and only depend on the phonological system of a given language (Ladefoged, Johnson 2014).

Microprosody, on the other hand, is a term used to refer to segmental level characteristics of speech and how these relate to higher level prosody. The phonetic characteristics of segments, i.e., their duration, fundamental frequency (F0) and intensity values depend on their manner and place of articulation. These are also referred to as *intrinsic duration*, *intrinsic F0* and *intrinsic intensity*, respectively (Kirby, Ladd 2016; Lehiste 1970; Vainio, Altosaar 1998; Whalen, Levitt 1995). Since the differences are caused by speech mechanics and reflect the properties of articulatory movements, the intrinsic duration, F0 and intensity associated with certain segments are claimed to be universal (Ohala 1983). For instance, several studies have shown that high vowels are shorter and have higher F0 values than low vowels (Gonzales 2009; Heuft, Portele 1995; Meister, Werner 2006; Whalen, Levitt 1995). As for consonants, obstruents are found to be longer than sonorants, and bilabials longer than coronals and velars (Fischer-Jørgensen 1964; Keating, Linker, Huffman 1983; Lisker 1972; Mendoza et al. 2003).

3.2. Geminate consonants

In the world's languages that exhibit quantity distinctions, the opposition is mostly binary, thus containing short and long length categories. Short consonants are also called single consonants or singletons, while long consonants are mostly referred to as geminates. The three-way consonantal quantity systems

are rare and can be described as having short consonants, long/half-long geminates and overlong/long geminates.

Languages can have geminates in different positions: word-initial, word-medial and word-final positions. The most common are geminates in word-medial intervocalic position. It has been argued that geminates in word-medial positions are perceptually more salient (Dmitrieva 2012; Kawahara 2005; Pajak 2010). For instance, geminates in all three positions occur in Tashlhiyt Berber (Ridouane 2007, 2010; Ridouane, Hallé 2017) and Maltese (Galea 2016), initial and final geminates in Trukese (Hart 1991), word-initial geminates can be found in Kelantan Malay (Hamzah, Fletcher, Hajek 2016), Cypriot Greek (Muller 2001) and Swiss German (Kraehenmann, Lahiri 2008), and word-final geminates exist in Jordanian Arabic (Abu-Abbas, Zuraiq, Abdel-Ghafer 2011; Al-Tamimi, Abu-Abbas, Tarawnah 2010). A detailed overview of the phonetic characteristics of geminate consonants is given in the study of Hamzah (2013), which investigates geminates in word-initial position in Kelantan Malay. The phonetic and phonological aspects of geminate consonants in different languages are also discussed in various articles in Kubozono (2017).

The purpose of the following sections is to outline the main aspects of the phonetic properties of geminates in both two-way and three-way systems. Then, quantity systems in Estonian and Inari Saami are discussed in more detail.

3.3. Binary systems

The higher frequency of binary systems probably explains the greater amount of attention that has been given to these systems. Next, an overview of phonetic characteristics associated with geminates in different languages is given.

It is generally found that the most salient and universal phonetic correlate of geminates is the duration measured from the acoustic or articulatory signal. Geminates are found to be 1.5 to 3 times longer in duration than single consonants (Ladefoged, Maddieson 1996). This has been shown, for instance, for Japanese (Idemaru, Guion 2008), Italian (Loporcaro 1996; Payne 2005), Cypriot Greek (Tserdanelis, Arvaniti 2001), Maltese (Mitterer 2018), Finnish (Suomi, Toivanen, Ylitalo 2008), Hungarian (Ham 2001; Neuberger 2015, 2016), Lebanese Arabic (Khattab 2007; Khattab, Al-Tamimi 2014), Libyan Arabic (Issa 2015), Malayalam (Local, Simpson 1999), and the three Indonesian languages Buginese, Madurese and Toba Batak (Cohn, Ham, Podesva 1999). The exact amount by which geminates are longer than singletons differs cross-linguistically.

Other features of geminates also seem to be language-dependent. In a number of languages such as Italian (Esposito, Di Benedetto 1999; Turco, Braun 2016), Malayalam (Local, Simpson 1999), Libyan Arabic (Issa 2015), Lebanese Arabic (Khattab 2007), Moroccan Arabic (Ali, Lahrouchi, Ingleby 2008), Buginese, Madurese and Toba Batak (Cohn, Ham, Podesva 1999), there is an inverse relation between the duration of the first syllable vowel and the quantity of the following consonant, as vowels before geminates are shorter in duration than

before single consonants. The duration of the second syllable vowel does not change. In Japanese, on the contrary, vowels are longer before geminates than single consonants and vowels following geminates are shorter than following single consonants (Idemaru, Guion 2008; Takeyasu, Giriko 2017). Gemination does not affect the duration of vowels surrounding the consonant in Finnish (Doty, Idemaru, Guion 2007), Hungarian (Ham 2001), Lebanese Arabic (Ham 2001), and Cypriot Greek (Tserdanelis, Arvaniti 2001).

For stop consonants, voice onset time (VOT, i.e., the time period between the release of a stop consonant and the beginning of voicing) differs between short consonants and geminates in some languages. VOT is longer for singletons than for geminates in Finnish and longer for geminates than for singletons in Cypriot Greek (Arvaniti, Tserdanelis 2000 for Cypriot Greek; Doty, Idemaru, Guion 2007 for Finnish). For Hungarian (Neuberger 2015), Italian (Turco, Braun 2016) and the three languages of Indonesia mentioned above (Cohn, Ham, Podesva 1999) it has been found that the duration of VOT does not differ between singletons and geminates.

The patterns of fundamental frequency and intensity as well as vocalic quality in terms of gemination have been given less attention, but studies do exist. For instance, the quality of vowels surrounding geminate consonants has been studied in Malayalam and it was found that vowels are more peripheral in geminate context compared to vowels in non-geminate context (Local, Simpson 1999). In Japanese, the fall of F0 in the first syllable vowel (V1) is greater and the intensity of V1 is also higher in the context of geminates than of short consonants (Idemaru, Guion 2008).

3.4. Ternary systems

Three-way length contrasts for consonants exist in a small number of languages that belong to Finno-Ugric branch of the Uralic language family. In fact, according to Pajusalu et al. (2018), the western Uralic area (Finnic, Saami, Hungarian) generally exhibits contrastive length for consonants, while it is not characteristic of many central-eastern Uralic languages (Mari, Mordvin, Ob-Ugric, Samoyed and Permic languages). Consonant gemination is featured, for example, in Finnish, Karelian, Votic, Kildin Saami, Pite Saami, Hungarian and East Khanty (as summarized in Klumpp, Mazzitelli, Rozhanskiy 2018), but only some Finno-Ugric languages exhibit ternary oppositions. These include Estonian (Lehiste 2003), Livonian (Lehiste et al. 2008), Ingrian (Markus et al. 2013) and some Saami languages, namely Inari Saami (Bye, Sagulin, Toivonen 2009; Markus et al. 2013), North Saami (Baal, Odden, Rice 2012; Hiovain, Šimko 2019), Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014) and Skolt Saami (McRobbie-Utasi 2007). Note that it is not entirely clear whether Pite Saami (Lehtiranta 1992; Wilbur 2014) and Ume Saami (Schlachter 1958; von Gertten 2015) exhibit three-way distinction of consonantal quantity.

Historically, short and long geminates occurred at the boundary of stressed and unstressed syllables already in late proto-Finnic (Lehtinen 2007) and became phonologically distinctive in Estonian and Livonian. The third, overlong quantity in Estonian emerged through the apocope and syncope of the unstressed short vowels (Lehiste 2003; Pajusalu 2012). These kind of sound changes did not happen in Finnish, which otherwise had a similar prosodic structure to Estonian (Lehiste 2003; cf. Lehiste 1965 for comparison of Estonian and Finnish quantity).

Livonian has the three-way quantity distinction between short consonants, short geminates and long geminates in intervocalic position at the boundary of stressed and unstressed syllables of disyllabic feet. The three-way distinction occurs after short vowels. Vowels after short geminates are longer than after long geminates (Lehiste et al. 2008; Markus et al. 2013). Similar to Estonian, quantity distinction in Livonian can be characterized by duration ratios of stressed and unstressed syllables (albeit the three-way distinction is not manifested in all cases). In feet with a short first syllable vowel, the duration ratio of short consonants to short geminates is 1.49, and the ratio of long geminates to short geminates is 1.78. In addition, Livonian has tonal opposition between plain and broken tone (also called *stød*) in primary-stressed syllables, which differentiates word meanings in certain word structures, including words with short vowels followed by voiced geminates or consonant clusters, for instance, *kallõ* 'island, part.sg', *ka'llõ* 'fish, part.sg' (Tuisk 2016).

In Ingrian, the ternary quantity distinction of consonants occurs after short and long vowels (Markus et al. 2013). Historically, several lengthening processes occurred that were different from other Finnic languages. Originally, Ingrian had the opposition of short consonants and geminates (Viitso 1997); consonants between short V1 and long V2 lengthened and formed primary geminates. Secondary geminates arose due to further lengthening in feet with long or closed first syllables and with long V2 (Gordon 2009). Elena Markus (2011) points out that while phonetically, Ingrian has five durational types of consonants, phonologically there are three contrastive types called single consonants, short geminates and full geminates. According to the later phonetic results of Markus et al. (2013) the duration ratio of short geminates to short consonants is 2.42 and the ratio of long geminates to short geminates is 1.30. The durations of V1 and V2 do not significantly differ in terms of the quantity of the intervocalic consonants. However, the general patterns showed that the duration of V2 is longer in word structures with short consonants compared to both short and long geminates (Markus et al. 2013). Previous studies on gemination in Ingrian have shown somewhat different results that could suggest that there is some variation between speakers with different dialectal backgrounds (cf. Gordon 2009; Markus 2010, 2011).

Regarding Saami languages, the distinction between short consonants, half-long and long geminates occurs at the boundary of stressed and unstressed syllables. For Inari Saami (Bye, Sagulin, Toivonen 2009) and Skolt Saami (McRobbie-Utasi 2007), the duration ratio of half-long geminates to short

consonants is less than two, and for Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014) and North Saami (Bals, Odden, Rice 2007; Hiovain, Šimko 2019) it is more than two. The duration ratio of long geminates to short geminates is the smallest in North Saami (Bals, Odden, Rice 2007) and Inari Saami (Bye, Sagulin, Toivonen 2009) being around 1.22 and 1.33, respectively, and greater for Skolt Saami (McRobbie-Utasi 2007) and Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014), with a ratio of around 1.5. The three-way quantity opposition is also manifested by correlations between intervocalic consonants and the surrounding vowels: while the duration of V1 in North and Skolt Saami is shorter when it is followed by a geminate compared to a short consonant, the durations of both vowels in Inari and Lule Saami are affected by consonantal length and shorten when the quantity of the intervocalic consonant increases.

In the following sections, the ternary quantity systems in Estonian and Inari Saami are described in more detail. Since this thesis studies the phonetic aspects of these three-way quantity systems, the following descriptions mainly focus on previous findings regarding the phonetic properties of quantity.

3.4.1. Estonian quantity

The Estonian three-way length distinction is a complex prosodic feature combining durational and tonal characteristics as well as involving both vowels and consonants. Ilse Lehiste (1960) describes Estonian quantity as a foot level phenomenon by showing the relations between stressed and unstressed syllables of a disyllabic foot. Other phonological discussions of quantity have assigned it to a syllable (Ehala 2003; Hint 1997; Viitso 2003). According to Tiit-Rein Viitso (2003), the stressed syllables of disyllabic feet can have three quantity degrees depending on the length and weight of the syllable. Short and light syllables form quantity 1, long and light syllables belong to quantity 2, and long and heavy syllables to quantity 3. Later phonological analyses stem from the syllable-level approach and incorporate it with foot-level (Prillop 2013, 2015, 2018a, 2018b). According to Külli Prillop (2018a), Q1 and Q2 feet are disyllabic, while the stressed syllable of Q3 constitutes a foot on its own.

The various ways of combining quantity in Estonian can be illustrated with the following examples:

Quantity 1 (Q1): short V1 short C2 [sɑte] ‘fall-out, nom.sg’.
Quantity 2 (Q2): long V1 short C2 [sɑːte] ‘broadcast, nom.sg’,
short V1 long C2 [sɑtte] ‘sediment, nom.sg’,
long V1 long C2 [sɑːtte] ‘get, pl. 2 pers.’.
Quantity 3 (Q3): overlong V1 short C2 [sɑːːte] ‘haystack, part.pl’,
short V1 overlong C2 [sɑtːte] ‘sediment, gen.sg’,
long V1 overlong C2 [sɑːtːte] ‘broadcast, gen.sg’.

Phonetic studies on the Estonian three-way quantity distinction have focused on the domain of quantity and its phonetic properties. Lehiste (1960, 1990, 1997, 2003) has shown that Estonian quantity can be best described by the duration ratios of the stressed syllable rhyme and the unstressed syllable nucleus in a disyllabic foot. The duration ratios are roughly 2/3 for Q1, 3/2 for Q2 and 2/1 for Q3. The duration of the first syllable (S1 rhyme) is calculated as the duration of the vowel (V1) or the sum of the durations of V1 and the following consonant (C2) for words with consonantal quantity. The syllable onset consonants are excluded from the calculations since they do not have length oppositions.

This way of describing quantity by comparing duration ratios of syllables has been criticized by Hartmut Traunmüller and Diana Krull (2003) who say that, among other reasons, in perception the syllable boundary inside long and overlong geminate consonants is not detectable by a listener. They propose that quantity is rather perceived by comparing the durations of segments in sequences: the duration of V1 is compared to the weighted sum of the durations of the following segments in a foot. Nevertheless, the authors do not give a clear model for describing Estonian three-way quantity. A similar, but more precise approach is taken by Arvo Eek and Einar Meister (2003, 2004), who have suggested that quantity is perceived by comparing the durations of vowels in both stressed and unstressed syllables with the coda of the stressed syllable. Syllable onset consonants depend on the local speaking rate. This model still remains unclear about the syllable boundary in the case of geminates in C2 position.

Returning to the model of Lehiste (1960), the method of comparing the syllable duration ratios has been used in many subsequent studies and has proven to be the most robust way of describing Estonian quantity, at least regarding feet where quantity is carried by the vowel, diphthong or consonant cluster (Krull 1992; Lippus et al. 2013).

Lippus et al. (2013) have investigated segmental durations in spontaneous Estonian, including words with intervocalic consonant clusters. They show longer first syllable rhyme durations for closed syllables compared to the open ones, and longer for Q3 compared to Q2 syllables. The mean durations of the coda consonants are longer in Q3 vs. Q2 and the onset of the second syllable is the shortest in Q2 compared to other quantities. According to the mean durations of the segments presented in their study, the intervocalic singletons seem to be of similar length with the S2 onset consonants of Q3 feet, but longer compared to the ones in Q2 feet. The duration of V1 does not differ remarkably before Q2 and Q3 consonant clusters, while V2 is shortened after Q3 clusters (it could be assumed that geminates behave as intervocalic consonant clusters).

The F0 contour is also important for distinguishing quantity degrees: it starts to fall near to the end of the first syllable in Q1 and Q2 words, but for Q3 the fall occurs remarkably earlier, at the beginning of the first syllable (Lehiste 2003; Lippus et al. 2013). For spontaneous speech, Krull (1998) has also found that the fall of F0 in Q3 is neutralized and listeners probably have to rely on context. Lippus et al. (2013) found that in spontaneous speech the fall of F0 in Q3 is neutralized in deaccented words. Describing the patterns of fundamental

frequency associated with Q2 and Q3, Lehiste (2003) states that in words with an overlong consonant preceded by a short vowel, a falling pitch cannot be realized because the vowel is too short. It might be that in words with consonantal quantity the distinction is made based on durational correlates only. In fact, perception tests (Lippus et al. 2007, 2009) have shown that in words with intervocalic geminate plosives where the pitch cue is missing, the temporal structure of the word is sufficient for perceiving all three quantity degrees.

Vocalic quality has been shown to vary with quantity. Lippus (2010) studied the vocalic quality and segmental durations in disyllabic words with open syllables in three quantity degrees. The data were taken from spontaneous speech, and segmental durations along with the vowel mid-point formant frequencies for the first four formants (from F1 to F4) were measured. The results showed that the stressed first syllable vowels were centralized in Q1 feet and vowels in Q2 and Q3 feet were located at the periphery of the formant space. The unstressed vowels did not vary remarkably. A later study of Lippus et al. (2013) found that vocalic quality depends on the duration of the vowel, but not on its quantity.

In the 1970s, Arvo Eek studied Estonian quantity in terms of the quality of different consonants. Eek (1974), using read speech, measured the durations of different intervocalic consonants in /ɑ-ɑ/ vocalic context and in three quantity degrees. Eek's results showed that the durations of intervocalic consonants differed depending on the consonant in all three quantity degrees: the longest were bilabials /p/ and /m/ and the shortest were /n/ and /r/. While Eek (1974) did not vary vocalic context in his study, Lippus and Šimko (2015) showed that durational patterns of the ternary consonantal quantity in Estonian exhibited different patterns as a function of vocalic context and the word-initial consonantal context. In many cases, the quantity effects were evened out in the interactions between quantity and segmental context. The results of publication [P2], which are discussed in section 4.2. of this thesis, showed similar trends in spontaneous Estonian. This topic is further studied in publication [P3] and discussed in section 4.3. The latter study adds different intervocalic consonants and investigates their interactions between quantity and vocalic contexts.

From an articulatory point of view, Eek (1970a) discusses some coarticulatory patterns of Estonian sonorant consonants and concludes that in the case of Q3 sonorants, the production of the first part of a geminate is more tense than the second part of a geminate. In the case of Q2 geminates, the first part of a geminate is lax. In his other studies, Eek investigated the articulation of Estonian sonorant consonants in more detail (1970b, 1970c, 1971a, 1971b, 1971c). The results showed that the production of geminates was characterized by a greater contact area between the tongue and the palate compared to the production of single consonants, but no ternary patterns were found. Einar Meister and Stefan Werner (2015) repeated the study with modern measuring equipment and came to the same conclusion. Lehiste et al. (1973) used electromyography to track the movements of the orbicularis oris muscle while producing geminate consonants in Estonian. They found two successive peaks in the signal for long geminates

and three or even four peaks for overlong geminates. However, this pattern was not systematic.

The articulatory study of Estonian geminates in publication [P1] gives new insights into ternary consonantal quantity in different contexts. These results will be discussed in the results section of this thesis after introducing the main findings about consonantal quantity in Inari Saami, a language that exhibits a three-way consonantal quantity system somewhat similar to Estonian.

3.4.2. Inari Saami quantity

The three-way quantity distinction in Inari Saami involves consonants, while vowels in stressed syllables can be short or long and vowels in unstressed syllables are short only. Geminates occur in the intervocalic position at the boundary of stressed and unstressed syllables of disyllabic feet. According to Patrik Bye (2007), all consonants in the Inari Saami consonant phoneme inventory exist as geminates. The ternary consonantal quantity contrast is manifested in the distinction between short consonants (Q1), half-long geminates or consonant clusters (Q2), and long geminates or consonant clusters (Q3) (Äimä 1914; Itkonen 1971; Itkonen, Bartens, Laitinen 1989; Sammallahti 1998; Sammallahti, Morottaja 1993).

The possible quantity combinations of Inari Saami disyllabic feet are illustrated with the following examples:

short V1, short C2 [sɑre] ‘blueberry, acc./gen.sg’.
short V1, half-long C2 [sɑrre] ‘blueberry, nom.sg’.
short V1, long C2 [pæl:lu] ‘ball, nom.sg’,
long V1, short C2 [mææli] ‘soup, acc./gen.sg’,
long V1, half-long C2 [mæælli] ‘soup, nom.sg’,
long V1, long C2 [mææl:lid] ‘soup, part.sg’.

Compared to the number of studies on the ternary quantity system in Estonian, quantity in Inari Saami has been given remarkably less attention. Phonological aspects of Inari Saami are discussed in Erkki Itkonen (1971) and Pekka Sammallahti (1984). A few phonetic studies have also been done and these have researched the durational properties of quantity. Bye, Sagulin and Toivonen (2009) studied the acoustic realization of quantity in Inari Saami in different foot structures with sonorants in the intervocalic position. Their results showed that the three-way distinction in consonant duration occurs after a short V1, while after a long V1 their results indicated that there is considerable variation between test subjects, as some produced a three-way distinction and some only a two-way distinction. The authors point out that these differences are explained by the dialectal background of the speakers: while the speakers from the western dialect area exhibit a three-way quantity distinction after a long V1, the speakers from the eastern dialect area do not.

Bye, Sagulin and Toivonen (2009) also studied correlations between the length of the intervocalic consonant and the surrounding vowels. In feet with both short and long V1, the duration of V1 was found to be inversely correlated with C2 duration, i.e., the longer the C2, the shorter the V1. However, this was not the case for all five speakers in the study. Regarding V2, the main pattern was that in feet with a short V1, the duration of V2 was shortened after half-long and long geminates, and in feet with a long V1, the duration of V2 was similar after short consonants and half-long geminates. For some speakers V2 was longer after long than half-long geminates. The authors suggest that this could be caused by the different prosodic structure in these words in which the second syllable bears secondary stress.

The study of Markus et al. (2013) investigated consonantal quantity in Inari Saami disyllabic feet with a short V1. They had one Inari Saami speaker, whose speech data was combined with the data from Sagulin (2008; also cf. Bye, Sagulin, Toivonen 2009), resulting in 6 test subjects. The results confirmed the three-way distinction in consonant duration. The inverse correlation between the durations of V1 and the following consonant was found, albeit with some variation. A shorter V2 following long geminates compared to half-long geminates was shown.

Taken together, the results of previous studies on the phonetic manifestation of consonantal quantity in Inari Saami indicate a considerable amount of variation. It is not completely clear how consonantal quantity is realized in feet with long vowels in the first syllable. In addition, the roles of fundamental frequency and intensity measurements in the realization of quantity have not been studied in Inari Saami. The investigations in Türk et al. (2014, 2015, 2016) and in publication [P4] help to fill this gap and understand the three-way quantity system in Inari Saami.

4. RESULTS AND DISCUSSION

In this chapter, the results of the publications [P1], [P2], [P3] and [P4] are discussed. The articulatory properties of Estonian quantity studied in publication [P1] are considered first, followed by the acoustic characteristics of consonantal quantity investigated in publications [P2] and [P3] for Estonian and in [P4] for Inari Saami. The acoustics of quantity in Estonian are discussed from temporal aspects, and in the case of Inari Saami, temporal and non-temporal properties of quantity are examined. After this, a short summary of ternary quantity characteristics in Finnic and Saamic languages is provided. Then, the second part of this chapter provides a discussion of the interactions between segmental context and quantity in Estonian from both articulatory and acoustic points of view. In addition, the brief findings concerning interactions between word and utterance-level prosody in Inari Saami are presented. Finally, some of the methodological aspects are discussed in the last section of this chapter.

4.1. Articulation of consonantal quantity in Estonian

This section deals with the articulatory characteristics of Estonian consonantal quantity discussing the results of publication [P1]. The purpose of this study was to capture the articulatory characteristics that reflect the three-way quantity distinction. The data were recorded using electromagnetic articulography (EMA), which is a modern and relatively precise way of tracking the movements of articulators. In fact, the articulatory study in [P1] is the first EMA study on Estonian. The effects of quantity on duration, displacement and velocity of lip closing and lip opening movements for the intervocalic consonant /p/ were analyzed along with the lingual transition gesture for the surrounding vowels. In addition, the timing of consonantal and lingual gestures was investigated. The kinematic properties of the gestures were calculated as follows: gesture duration was calculated as the duration of the interval from movement onset to its offset; displacement was the Euclidean distance between the signal value at a gesture's onset and its offset; and peak velocity was the maximum of tangential velocity during a gesture's onset-offset interval.

4.1.1. Lip closing, lip opening and tongue transition gestures

Earlier studies have shown no clear ternary patterns in the articulation of Estonian sonorant consonants (Eek 1970a, 1970b, 1971a, 1971b, 1971c; Meister, Werner 2015). The results of [P1] supported previous findings and also showed variation in the realization of quantity in terms of the kinematics of articulatory gestures. Figure 1 illustrates the duration, displacement and velocity of the lip closing gesture. The most consistent patterns were found for the duration of the lip

closing movement: this was longer when the quantity of the intervocalic consonant increased. The three-way distinction was revealed for the stimuli with an /i-ɑ/ vocalic context. The displacement of the lip closing gesture was also greater in the case of Q2 and Q3 compared to the short quantity degree, i.e., there was no difference between Q2 and Q3. Peak velocity for the lip closing gesture was not affected by quantity.

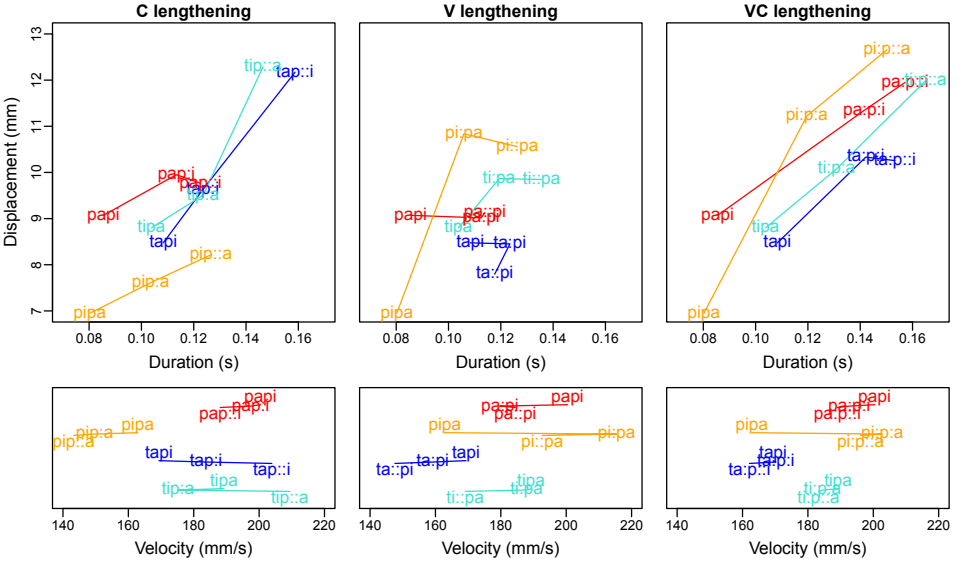

Figure 1. Duration (x-axis of upper panels), displacement (y-axis of upper panels) and peak velocity (lower panels) of the lip closing gesture for different stimuli.

These results indicate that during the longer acoustic closure of the bilabial intervocalic consonant there is more time for the articulatory lip closing movement which, accordingly, is longer in Q2 and Q3. These general patterns of longer and larger lip closing gestures for geminates compared to short consonants have also been found in other languages with two-way length distinctions, for instance, in Japanese, Tashlhiyt Berber and Moroccan Arabic (Löfqvist 2007; Ridouane 2007; Zeroual, Hoole, Gafos 2008). The lack of clear ternary patterns in the gestures seems to occur due to segmental context.

The variation in the kinematics of the lip opening gesture was induced by the differences in the vocalic quantity only: the lip opening gestures were shorter and smaller for Q3 compared to Q1 and Q2. This could be due to the compensatory durational alternations of V2 in relation to V1, as V2 is shortened when V1 is long, and vice versa (Lehiste 2003). This indicates that during the shorter vowel there is also less time for opening the lips.

The distinctiveness of Q3 seemed to be realized in the characteristics of the lip opening gesture, which was shorter and smaller compared to Q2. This could lend support to the phonological accounts about Q3 feet suggested by Prillop (2013, 2015): a stressed syllable of a Q3 foot constitutes a foot on its own and

the unstressed syllables are reduced since they do not belong to the foot. However, this pattern with shorter and smaller lip opening gestures in Q3 feet was only found in the case of stimuli where vocalic quantity varied and the intervocalic consonant was short.

Publication [P1] also studied the lingual transition gestures of the vowels adjacent to the bilabial consonant. The lingual transition was longer and slowed down when the intervocalic consonant was longer. Q3 was distinguished from Q1 and Q2. This suggests that the lingual gestures for vowels and lip gestures for the consonant are produced separately while overlapping in time (cf. Fowler, Saltzman 1993).

4.1.2. Inter-gestural coordination

The data in publication [P1] made it possible to study the timing of the vocalic and consonantal gestures in terms of quantity. The duration of the time interval between the onset of the lip closing gesture for the intervocalic bilabial consonant and the onset of the lingual gesture for the following vowel was studied. Results are illustrated in Figure 2. The time interval was longer when the consonantal quantity increased, and shorter when the vocalic quantity increased, i.e., the tongue started moving later with respect to the closing movement of the lips in words with different consonantal quantity, and earlier in words with vocalic quantity (cf. Figure 2).

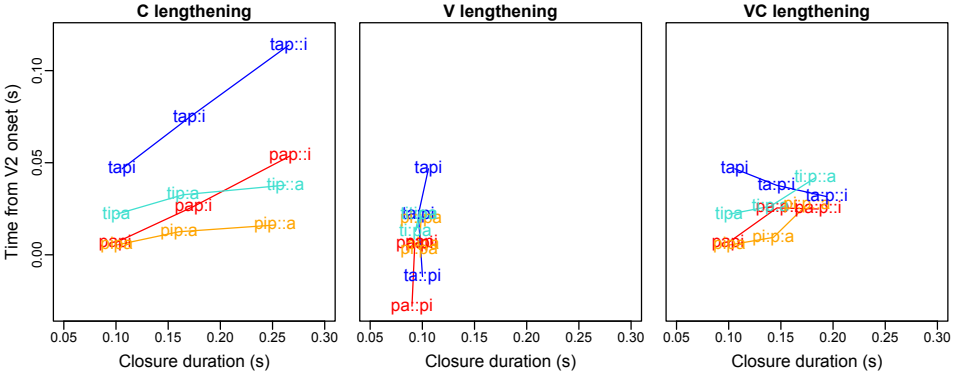

Figure 2. The displacement of the lip closing gesture vs. the duration of the interval for the lip-tongue movements.

Moreover, the distinction was three-way in stimuli with /t/ as the word-initial consonant and in an /ɑ-i/ vocalic context. Šimko et al. (2014) studied the lip-tongue coordination for Finnish short and geminate consonants and also found a longer interval for geminate consonants than for single consonants. Thus, it could be that the lingual transition starts later due to the longer duration of geminate consonants where the closure is longer than in the case of short consonants where there is less time for the lingual gesture to start. In addition,

this kind of pattern has been reported for Japanese (a mora-timed language), where the timing of the lingual gesture is connected to the length of the intervocalic consonant (Smith 1995; cf. Löfqvist 2006, 2017 for different results) as opposed to the theory of continuous production of vowels where vowels are not affected by consonantal length (Öhman 1966). Such patterns are found for Italian which has been considered a syllable-timed language (Smith 1995). With this regard, the results of publication [P1] show similarities to a mora-timed language like Japanese.

4.2. Acoustics of consonantal quantity in Estonian and Inari Saami

In this section, the acoustic characteristics of ternary consonantal quantity in Estonian and Inari Saami are discussed based on the results found in publications [P2], [P3] and [P4]. In addition, article [P1] is mentioned as well because it briefly considers the acoustic duration of consonants in Estonian.

Publications [P2] and [P3] investigate the temporal aspects of consonantal quantity in Estonian considering the underlying segmental context using the data from the Phonetic Corpus of Estonian Spontaneous Speech. Article [P2] focuses on the temporal manifestations of consonantal quantity as a function of consonant quality, and article [P3] describes the three-way interactions between consonantal and vocalic context and quantity. Publication [P4] studies consonantal quantity in Inari Saami analyzing data from read speech and considering both temporal and non-temporal aspects of quantity.

4.2.1. Duration in Estonian and Inari Saami

The durational properties of three-way consonantal quantity in Estonian and Inari Saami are presented next. First, the durations and duration ratios of Estonian intervocalic consonants in three quantity degrees are discussed in section 4.2.1.1. Then, the segmental durations and duration ratios of segments in Inari Saami disyllabic feet are dealt with in section 4.2.1.2.

4.2.1.1. Duration in Estonian

Publication [P1] briefly deals with the acoustic duration of the intervocalic stop using repeated words as test material recorded in parallel with the articulatory data. The results yield a clear three-way distinction in consonant duration (cf. x-axis in Figure 2). When quantity is carried by both vowels and consonants (cf. the right panel in Figure 2), the durational differences are smaller, but still exist (cf. the left panel in Figure 2 with alternating consonantal quantity only).

In publications [P2] and [P3], the durational aspects of Estonian consonantal quantity were studied concerning the quality of the intervocalic consonant and

surrounding vowels. Figure 3 shows the durations of each segment in a disyllabic foot broken down by quantity and quality of the geminating consonant.

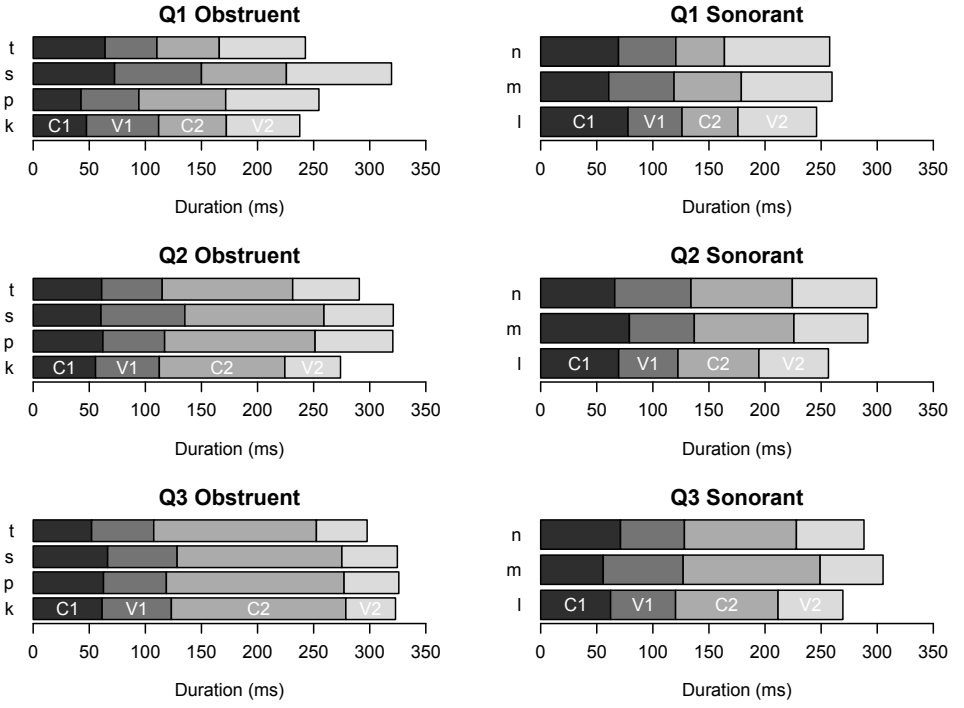

Figure 3. The durations of all segments in Estonian disyllabic feet with different intervocalic consonant quality and quantity.

As can be seen in Figure 3, the durations of intervocalic consonants in Q2 are longer than in Q1, and in Q3 the durations are longer than in Q1 and Q2. However, the differences between quantity degrees for different consonants vary depending on the place and manner of C2. This is illustrated in Table 4 by the duration ratios of Q2/Q1, Q3/Q2 and Q3/Q1 for words with different intervocalic consonants.

In addition, the difference between quantities is shown in the duration of V2 that is negatively correlated with the duration of the preceding consonant: while the durations of intervocalic C2 consonants increase, the durations of the following V2 vowels decrease.

As mentioned above, Table 4 presents the duration ratios of quantity degrees in the case of different intervocalic consonants. Generally, the duration ratio of Q2 geminates to Q1 consonants is 1.5, while the ratio of Q3 geminates to Q2 geminates is a bit smaller at 1.4. The ratio of Q3 geminates to Q1 consonants is 2.1.

Table 4. The duration ratios of Q2/Q1, Q3/Q2 and Q3/Q1 for different consonants.

Consonant	Q2/Q1	Q3/Q2	Q3/Q1
/p/	1.7	1.2	2.1
/t/	2.1	1.3	2.6
/k/	1.9	1.4	2.6
/s/	1.6	1.2	1.9
/m/	1.5	1.4	2.0
/n/	2.1	1.1	2.3
/l/	1.4	1.3	1.8
Overall	1.5	1.4	2.1

The data from spontaneous speech are similar to previous findings from read speech (Eek 1974), where Q3 geminates were also 1.4 times longer than Q2 geminates, but the differences between Q2 geminates and Q1 consonants were different – in read speech, Q2 geminates were 2 times longer than Q1 consonants. The ratio of Q3 geminates to Q1 consonants was 2.7.

4.2.1.2. Duration in Inari Saami

The durational aspects of three-way consonantal quantity in Inari Saami are discussed in publication [P4]. The main question was how the three-way consonantal quantity distinction is realized in different word structures. For this, the durations of segments in disyllabic feet were analyzed along with the duration ratios of segments.

The results of [P4] showed that three-way consonantal quantity in Inari Saami was realized by the duration of the intervocalic consonant (C2) and the relations between C2 and both neighboring vowels. Figure 4 presents the mean durations of all segments in disyllabic feet with different structures. As can be seen in the figure, the three-way distinction was most clearly realized in consonant duration in feet with a short V1. Differences between consonant durations in different quantities showed a clear separation between Q2 and Q3 geminates as, in fact, the ratio of Q3 to Q2 geminates (the ratio of 1.82) was greater than the ratio of Q2 geminates to Q1 consonants (1.53).

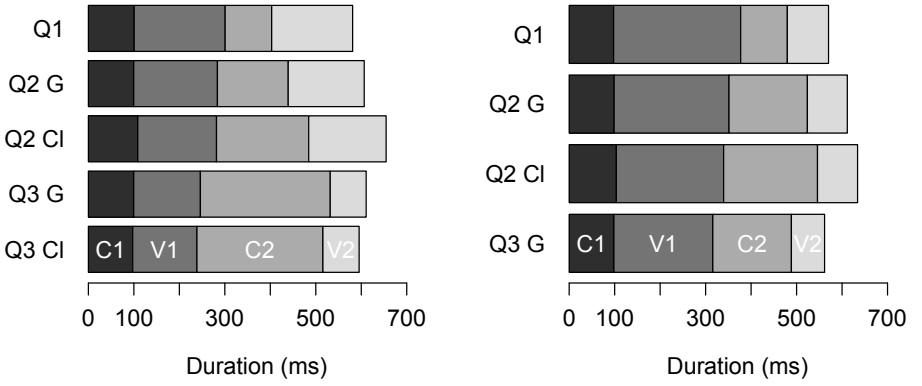

Figure 4. The average durations of all segments in disyllabic feet. Word structures with a phonologically short V1 are presented in the left panel, and those with a long V1 in the right panel. G denotes geminates and Cl consonant clusters.

In addition to differences in consonantal duration, the durations of the vowels surrounding the consonant decreased when consonantal quantity increased. This is illustrated in Figure 5, which shows the duration ratios of V1/C2 and V2/C2. In feet with a long V1, the durations of Q2 and Q3 geminates did not differ, while the durations of both surrounding vowels shortened when consonantal quantity increased. This shows that the three-way quantity distinction is still found in foot structures with a long V1, but the distinction is manifested in the duration of vowels. The results found in publication [P4] suggest that the ternary opposition of consonant quantity in Inari Saami is a foot level phenomenon and can be well described by the duration ratios of neighboring segments.

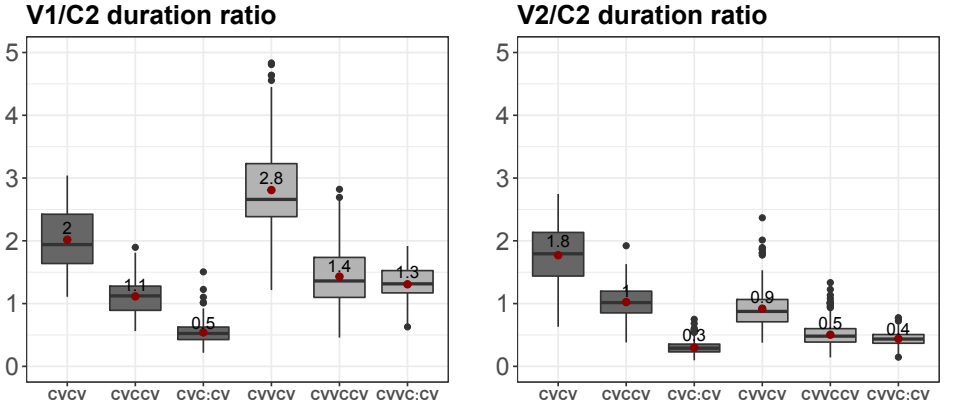

Figure 5. The duration ratios of V1/C2 (left panel) and V2/C2 (right panel) in different foot structures. The mean values of the ratios are denoted with a dot and a number above it.

The results in [P4] are somewhat different from the results found in Bye, Sagulin and Toivonen (2009) and could be explained by variation between speakers due to their different dialectal backgrounds. In general, the results coincide with the patterns previously found for other Finno-Ugric languages with the three-way consonantal quantity distinction. In Estonian and Livonian, a longer consonant is followed by a shorter vowel, while the duration of the preceding vowel does not depend on the length of the consonant (Lehiste 2003; Lehiste et al. 2008; Lippus et al. 2013). In North Saami (Magga 1984) and Skolt Saami (McRobbie-Utasi 2007), the duration of V1 shortens when the following consonant lengthens, whereas the second syllable vowel remains unaffected. In the case of Inari Saami and Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014) both vowels shorten when the quantity of an intervocalic consonant increases.

Table 5 compares the duration ratios of Q2 to Q1 (CC/C) and Q3 to Q2 (C:C/CC) in four Saami languages and two Finnic languages (word structures with a short V1). The differences between Q2 and Q1 are smaller in Inari Saami (the ratio is 1.53) and Livonian (1.49), while greater in other languages. Considering the differences between Q3 and Q2 consonants, Inari Saami stands out among all of the other languages by having a greater durational difference between Q3 and Q2 consonants.

Table 5. The duration ratios of Q2 to Q1 and Q3 to Q2 consonants in Saami languages and Finnic languages.

	Saami languages				Finnic languages	
	Inari (Türk et al. 2019)	**Skolt** (McRobbie-Utasi 2007)	**North** (Bals, Odden, Rice 2007)	**Lule** (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014)	**Estonian** (Markus et al. 2013)	**Livonian** (Markus et al. 2013)
Q2/Q1	1.53	1.87	2.30	2.39	2.19	1.49
Q3/Q2	1.82	1.53	1.22	1.50	1.4	1.52

In addition to temporal characteristics, non-temporal properties of quantity were studied in Inari Saami. While fundamental frequency and intensity characteristics have been studied in Estonian (Eek, Meister 1997; Kalvik, Mihkla 2010; Lehiste 2003; Lippus et al. 2013) and to a smaller scale in Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014), there are no previous studies about the contribution of these factors to quantity manifestations in Inari Saami. With this in mind, the aim of the following two sections is to present fundamental frequency and intensity patterns in Inari Saami.

4.2.2. Fundamental frequency in Inari Saami

It is known from previous studies on Estonian quantity that fundamental frequency movement plays a significant role in differentiating between long and overlong vocalic quantities (Lehiste 2003; Lippus et al. 2013). The sufficiency of the temporal structure of the word for perceiving three quantity degrees in the case of intervocalic geminate plosives has been shown in perception studies (Lippus, Pajusalu, Allik 2007, 2009). In Livonian, the significance of fundamental frequency movement on quantity has been shown to be relatively small (Tuisk 2012), and the same applies to Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014). For Finnish, Suomi et al. (2003) also report that F0 plays a minor role in the realization of quantity. However, different results are presented in Vainio et al. (2010), who found that in addition to duration, quantity in Finnish is signaled tonally as well. Note that the two latter studies were carried out with different theoretical and methodological viewpoints.

Fundamental frequency contours in Inari Saami words with different foot structures were studied in publication [P4]. Figure 6 illustrates the results for fundamental frequency contours in different foot structures in phrase-medial and phrase-final position.

As it can be seen from Figure 6, the results indicated no general patterns in F0 contours concerning different foot structures. However, small differences were observed. In words with a short V1, the slope of the fundamental frequency was shallower when a short vowel was followed by Q3 geminates compared to Q1 consonants or Q2 geminates. For these foot structures with Q3 geminates, the F0 in V2 had higher values than in the case of Q1 and Q2. The situation was reversed when there was a consonant cluster in the intervocalic position. In the case of Q3 consonant clusters after a short V1, the F0 contours fell lower in V2 than after Q1 consonants or Q2 consonant clusters. Therefore, there are some indications that fundamental frequency could contribute to distinguishing Q3 from Q1 and Q2.

The results are similar to Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014) and Livonian (Tuisk 2012), where fundamental frequency movement has been shown to play a minor role in terms of the quantity distinction. However, different theoretical and methodological approaches might have led to different results, as was the case for Finnish (cf. Suomi et al. 2003; Vainio et al. 2010).

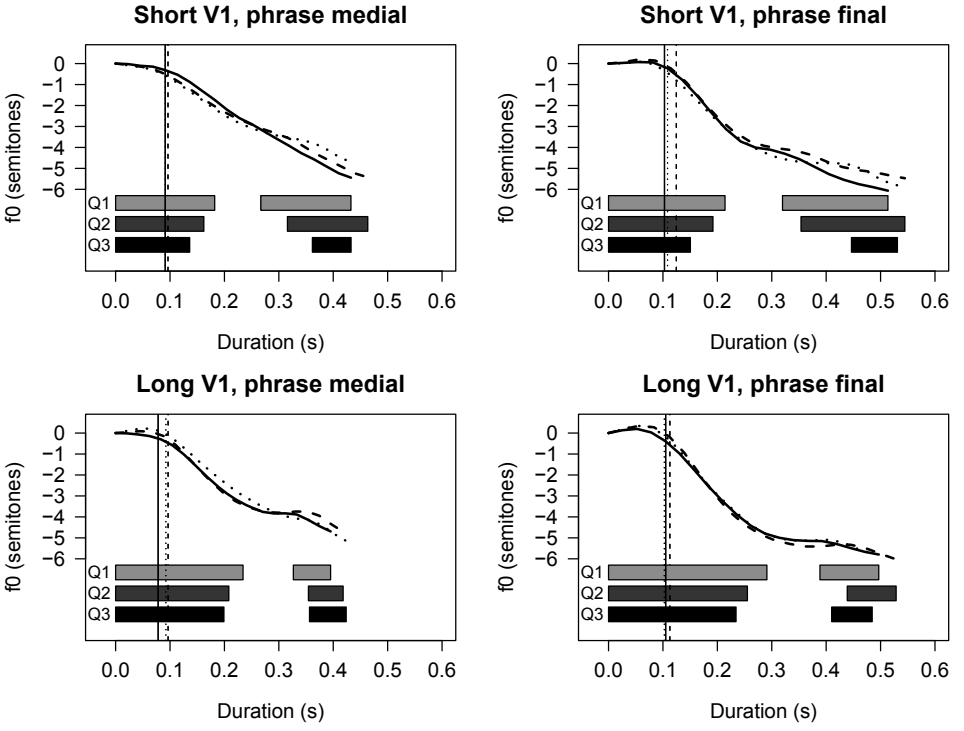

Figure 6. Fundamental frequency contours in Inari Saami disyllabic words with short and long V1 in phrase-medial and phrase-final positions of test sentences. Foot structures with short intervocalic consonants are denoted with solid contours, dashed contours stand for foot structures with half-long geminates/consonant clusters, and dotted contours for words with long geminates/consonant clusters. Vertical lines show the location of the F0 turning point and the marking of these corresponds to the F0 contours. The durations of V1 and V2 surrounding Q1, Q2 and Q3 consonants are shown with horizontal bars.

4.2.3. Intensity in Inari Saami

In publication [P4], the intensity characteristics of the intervocalic consonant and the surrounding vowels were studied in Inari Saami disyllabic words. Only words with intervocalic sonorant consonants were used for the analysis. The results indicated quantity-related differences in the intensity measurements for both V1 and V2 vowel. This is illustrated in Figure 7, which presents the intensity differences between V1 and V2 in different foot structures and two phrasal positions. In addition, the two panels on the left show the intensity differences in each word structure for each speaker. The intensity of V1 generally increased and the intensity of V2 decreased when the quantity of the intervocalic consonant increased. There was no effect of quantity on the intensity of the intervocalic consonant itself.

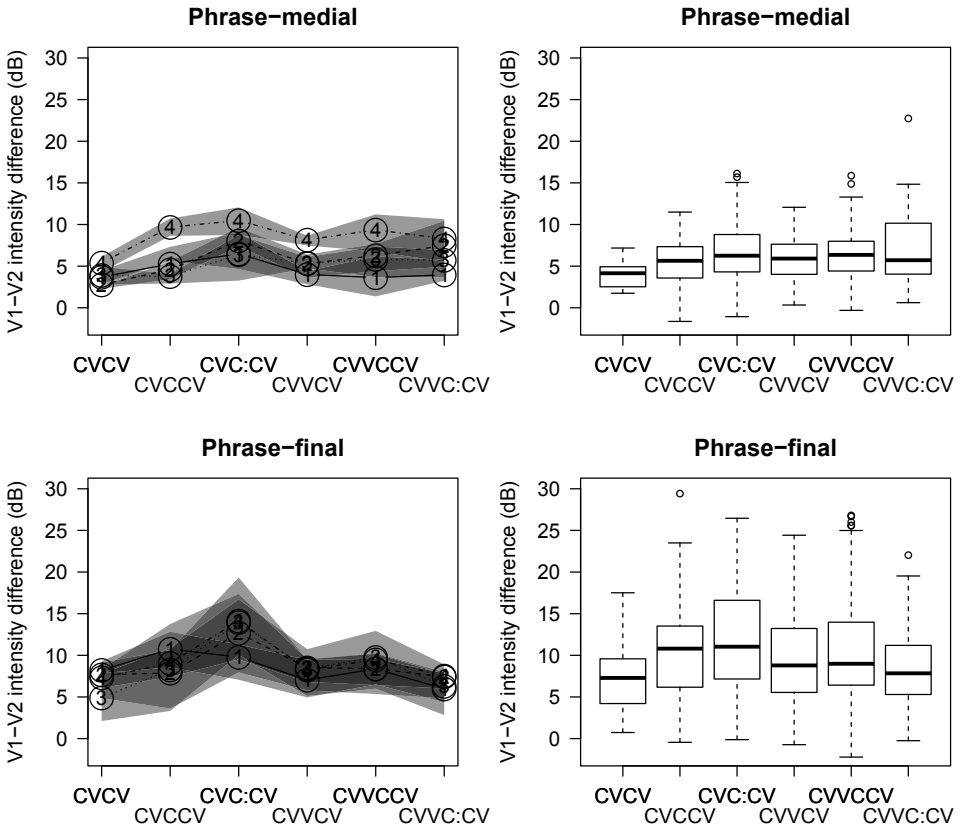

Figure 7. The difference between the intensity measurements of V1 and V2 (in dB) in different foot structures for each speaker (left panels) and across all speakers (right panels). The numbers in circles denote the mean values for the intensity difference for each speaker and the shaded areas show 25% and 75% quantiles (the darker the color the more overlap between speakers).

When discussing the results of intensity, it should be noted that intensity characteristics are strongly affected by the intrinsic characteristics of segments (Lehiste 1970), which may cause differences in the results of different studies that use different test material. The role of intensity in the realization of the ternary quantity distinction has been previously studied in Estonian (Eek, Meister 1997; Kalvik, Mihkla 2010) and Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014). For Livonian, intensity has been studied in connection with broken tone (*stød*) (Tuisk 2015).

The most similar results to those found in publication [P4] on Inari Saami have previously been obtained for Lule Saami, where the intensity of V1 and V2 depended on the foot structure. The intensity of V1 increased when the quantity of the following consonant increased, and the intensity of V2 decreased. As in Inari Saami, the intensity of the intervocalic consonant did not change remarkably (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014).

Different studies that have dealt with intensity characteristics in the manifestation of quantity in Estonian have shown varying results, suggesting that intensity is not connected to quantity realizations in a consistent way. Eek and Meister (1997) showed that the intensity difference between V1 and V2 was the greatest for Q3 feet: 3 dB for words with intervocalic plosives and 10 dB for words with intervocalic sonorants. The were no remarkable differences in the average intensity difference of V1 and V2 in Q1 and Q2 feet. Krull (2001) studied intensity in normal and whispered speech and reported a similar contour for both F0 and intensity: a falling contour for Q3 and flat or rising for Q2. Mari-Liis Kalvik and Meelis Mihkla (2010) found no remarkable differences in the intensity measurements of V1 and V2 for different quantities.

4.3. Summary of cross-linguistic differences

The results of different studies on three-way consonantal quantity show that the phonetic manifestation of this rare phonological phenomenon is language-specific. Table 6 presents a summary of different temporal characteristics of segments and non-temporal aspects describing three-way consonantal quantity in different Finno-Ugric languages.

Table 6. A comparison of factors contributing to the realization of three-way consonantal quantity systems for a selection of languages. "+" denotes that the factor is relevant, "–" shows that there is no connection, "?" indicates a gap in the studies.

	V1 duration	C2 duration	V2 duration	F0	Intensity
Estonian (Eek 1974; Eek, Meister 1997; Kalvik, Mihkla 2010; Krull 2001; Lehiste 2003; Lippus et al. 2013, 2009; Markus et al. 2013)	–	+	+	+	+/–
Livonian (Lehiste et al. 2008; Markus et al. 2013; Tuisk 2012; Tuisk, Teras 2009)	–	+	+	–	?
Inari Saami (Bye, Sagulin, Toivonen 2009; Markus et al. 2013; Türk et al. 2019)	+	+	+	–	+
Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014)	+	+	+	–	+
North Saami (Bals Baal, Odden, Rice 2012; Hiovain, Šimko 2019)	+	+	–	?	?
Skolt Saami (McRobbie-Utasi 2007)	+	+	–	+	+

In all of the languages presented, the duration of the intervocalic consonant increases when consonantal quantity increases. The duration of the first syllable vowel is inversely correlated with quantity in all four Saami languages where the three-way consonantal quantity distinction has been observed. In the Finnic languages Estonian and Livonian such a correlation has not been found. The duration of the second syllable vowel is also shorter after geminates than after short consonants in most of the languages, except in North Saami and Skolt Saami, where it is not affected by consonantal quantity.

Fundamental frequency and intensity characteristics in terms of consonantal quantity have not been studied as extensively as segmental durations. While fundamental frequency patterns vary in Estonian and are somewhat connected to quantity realization in Skolt Saami, F0 does not play a role in other languages (note that there is no information for North Saami). The observation that intensity features contribute to the realization of consonantal quantity has been made for Inari Saami and Lule Saami (and Skolt Saami). Varying results have been obtained for Estonian. In Livonian, the situation is also more complex since F0 and intensity patterns are connected to plain and broken tone in weak and strong grade words.

4.4. Interactions between segmental context and quantity

Publications [P1], [P2] and [P3] study the articulation and acoustics of Estonian consonantal quantity in varying segmental contexts. Publication [P1] deals with the articulatory characteristics of quantity considering different vocalic contexts (/ɑ-i/ vs. /i-ɑ/) and word-initial consonants (/p/ vs. /t/). In publication [P2] the durational properties of quantity were studied as a function of consonant quality, and publication [P3] extends this study by investigating the interactions between quantity and the quality of the intervocalic consonants and the surrounding vowels.

The results of [P1] showed that although a three-way quantity distinction was realized in the case of some articulatory movements, there were no consistent patterns that indicated manifestation of the phonological three-way length opposition on the articulatory level. There was variation depending on the word-initial consonant (/p/ vs. /t/) and vocalic context (/ɑ-i/ vs. /i-ɑ/). For some stimuli, Q2 and Q3 were opposed to Q1 and in other contexts Q1 and Q2 were opposed to Q3.

A three-way distinction was found for the duration of the lip closing gesture for the intervocalic bilabial /p/ in an /i-ɑ/ vocalic context; in this case, the lip closing gesture was longer when consonantal quantity increased. In an /ɑ-i/ context, the distinction was binary. In this vocalic context, Q3 was not different from Q2 in /p/-initial stimuli, but Q3 differed from Q2 in /t/-initial stimuli. This arises from the relationships between segmental context and quantity. As the lip closing gesture already starts during the previous vowel, the nature of the vowel could interact with the following consonant and its quantity characteristics. The

constrained nature of the preceding vowel /i/ can cause it to have less coarticulation with the following consonant as compared to the vowel /ɑ/ (Recasens, Espinosa 2009; Recasens, Pallarès, Fontdevila 1997). Therefore, in the case of /i/ in the stressed syllable, the three-way quantity characteristics exhibit less interaction with the preceding vowel than in the case of /ɑ/ as V1. The same could apply to /t/-initial stimuli compared to /p/-initial stimuli, namely that the consonant /t/ has relatively less influence on the neighboring segments.

Contextual effects also emerged in the tongue transition gesture from V1 to V2 in that it was longer in the case of Q3 vs. Q1 and Q2 in stimuli with the transition form /ɑ/ to /i/, while the duration of the tongue transition for /i-ɑ/ stimuli generally did not differ in different quantities. Moreover, a three-way distinction was found for /t/-initial /ɑ-i/ words: the tongue transition was longer in the case of higher quantity degree. A three-way distinction was also found for the peak velocity of the tongue transition gesture in /p/-initial /ɑ-i/ stimuli. The transition slowed down in Q2 and Q3. In other stimuli, Q2 and Q3 differed from each other by exhibiting a faster tongue transition gesture in the case of Q2. This shows again that the effects of quantity on the kinematic characteristics of articulatory movements are complex and manifested in the interactions of quantity and quality of segments.

The results of the acoustic studies in publications [P2] and [P3] also showed that quantity interacts with the intrinsic properties of the intervocalic consonants and the surrounding vowels. The estimated C2 durations as a function of interaction of quantity, C2 consonant and V1 height are shown in Figure 8. In all three quantities, sonorants were shorter in duration than obstruent consonants. This result was expected since several other studies have shown that it is a frequent pattern in different languages (Mendoza et al. 2003). The results indicated longer intrinsic durations for bilabials than for alveolars and velars. This finding coincides well with previous studies (Fischer-Jørgensen 1964; Haggard 1973; Keating, Linker, Huffman 1983; Lehiste 1970; Suen, Beddoes 1974).

The interactions between quantity and quality of the geminating consonant were shown as follows: in Q1, the intrinsic durations of consonants were more distinct than in Q2 and Q3, where the durations of obstruent consonants moved closer to each other. The duration of the bilabial sonorant /m/ was also closer to obstruents than to sonorants, and the durations of the sonorants /n/ and /l/ kept their distinctiveness. This might be caused by their sonorous nature making them prone to blending with flanking vowels more than spectrally distinct obstruent consonants (cf. Dmitrieva 2012; Pajak 2010).

Considering differences between quantities, the consonant durations in Q2 and Q3 overlapped in the cases of /p/ and /s/. The durations of Q2 and Q3 were close to each other in the cases of /t/ and /n/; the durations of Q1 and Q2 were close to each other for /m/ and /l/. As supported by the results in publication [P1], the coarticulatory effects between the intervocalic consonants and the surrounding vowels interacted with quantity. Consonants were generally longer after high and mid vowels than after low vowels, and longer as well before high and mid vowels than low vowels. The C2 durations for Q2 and Q3 often

overlapped for sonorant consonants preceded by mid or low vowels. This shows the greater coarticulatory effects of open vowels on sonorant consonants that, additionally, are not as resistant to coarticulation as obstruent consonants. However, obstruent consonants /p/ and /s/ were also somewhat overlapping in Q2 and Q3 following mid and low vowels.

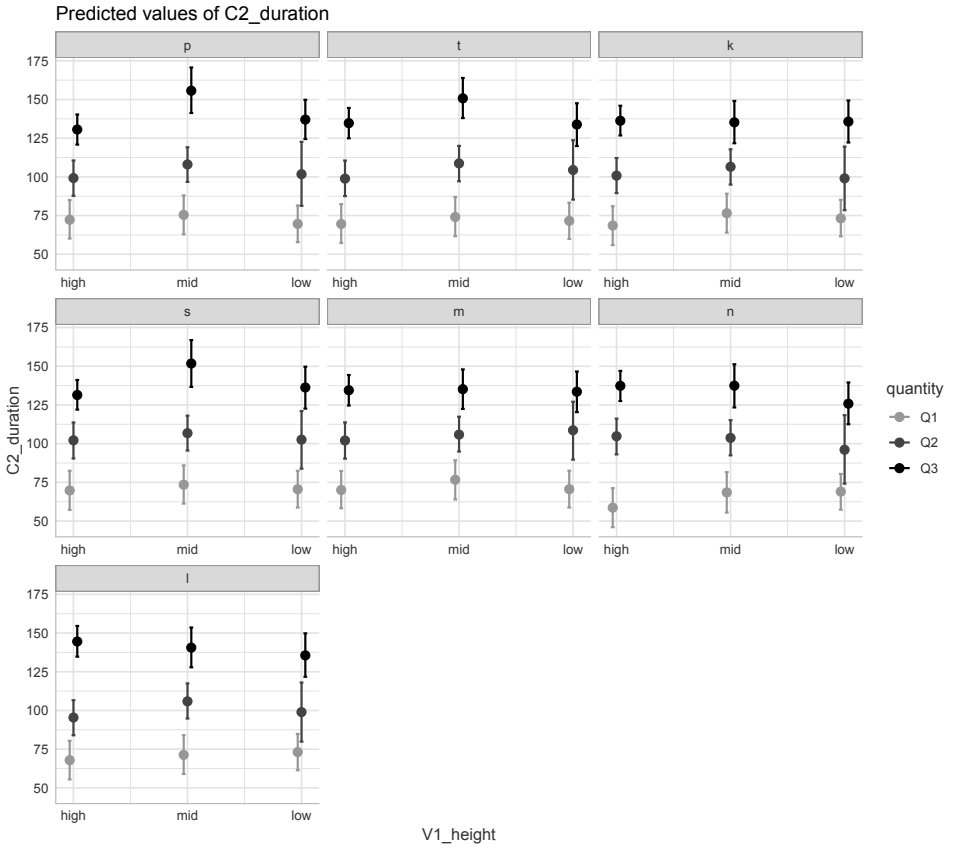

Figure 8. Model predictions for C2 duration (in milliseconds) as a function of C2 consonant type, V1 height and quantity interaction. The dots present the posterior means and the whiskers show 95% credible intervals.

The interactions between V2, the intervocalic consonant and quantity showed somewhat different patterns as quantity seemed to be affected more by high vowels. Q2 and Q3 were overlapping for /p/, /n/ and /l/ preceding high vowels, for /m/ preceding low vowels, and for /s/ in general. Q1 and Q2 were similar for /m/ and /l/ followed by high vowels as well. Broadly, the results of publications [P2] and [P3] confirm the results of Lippus and Šimko (2015), who also found that contextual effects are sometimes stronger than quantity alone. This may indicate that in perception and production context-dependency plays a significant role. For instance, Holger Mitterer et al. (2017; 2018) argue that pre-lexical processing is based on allophones and not abstract phonemes.

4.5. Interactions between word-level and utterance-level prosody

Word-level prosody can also interact with higher level prosody. For example, in Estonian it has been found that the position of a word in an utterance and whether or not it is stressed interact with quantity characteristics. The duration ratios of stressed and unstressed syllables have been shown to be stable in accented words, while less stable in deaccented words (Asu et al. 2009; Lippus et al. 2013).

Inari Saami data in publication [P4] were analyzed in two phrasal positions that were intended to elicit contrastive stress. The phrase-final position of a word in test sentences denoted contrastive stress and the phrase-medial position of a word denoted no contrastive stress. The results showed that the durations of all segments except C1 in disyllabic feet were longer phrase-finally than phrase-medially. This was found for feet with either a short or a long V1. However, there were no interactions between phrasal position and quantity. Regardless of the stress position the duration ratios of V1/C2 and V2/C2 in different foot structures remained the same. Therefore, the durational characteristics of quantity did not interact with stress conditions, while contrastive stress was indicated by longer segmental durations.

In addition, there were no clear patterns for interactions between quantity and fundamental frequency measurements. Based on the test material used in publication [P4], the F0 contours in Inari Saami are described by the H* target followed by an L tone, irrespective of whether there was contrastive stress. The F0 characteristics interacted with the phrasal position and were generally more enhanced in phrase-final than phrase-medial position, which reflects the effects of contrastive stress. The F0 range, i.e., the difference between the F0 maximum and minimum, was greater phrase-finally than phrase-medially, and the interactions between phrasal position and consonantal quantity showed that the F0 range was greater with long consonant clusters than with short consonants in phrase-final position, but not in phrase-medial position. In addition, the F0 turning point occurred later and the F0 slope was greater phrase-finally than phrase-medially.

The intensity values in Inari Saami indicated lower values in V2 for phrase-final position than for phrase-medial position, but did not show any interactions with quantity. In Estonian, Meelis Mihkla and Heete Sahkai (2017) studied the relations between sentence stress and quantity in terms of the maximum intensity values and found a significant interaction between these factors. The maximum intensity values were higher in the stressed position compared to unstressed one, but the contribution to quantity was not specified.

4.6. Methodological implications

The current thesis aims at dealing with ternary consonantal quantity in two Finno-Ugric languages using data from read and spontaneous speech. In addition, an alternative statistical approach to traditional statistics was undertaken in order to describe complex relations between different factors that could contribute to quantity manifestations in their own manner. In the next subsections, the implications of different methodological aspects used in the thesis will be discussed: first, using data from read and spontaneous speech; second, using traditional and Bayesian statistics.

4.6.1. Read and spontaneous data

In publications [P1] and [P4], read speech data were used and data in publications [P2] and [P3] were comprised of words taken from the phonetic corpus of spontaneous Estonian. There are advantages and disadvantages to both using read and spontaneous data when studying human speech. Yi Xu (2010) discusses the usefulness of lab speech and brings out advantages and disadvantages for spontaneous speech as well. Speech recorded in laboratories can be highly controlled for different factors, and these factors' contribution to variation of the phenomenon researched can be tested while keeping other factors constant. Most often, test subjects read aloud pre-written texts or sentences carefully planned by a researcher. The controlled nature of this type of speech makes it possible to get credible results. Spontaneous speech, on the other hand, represents the most natural way of speaking and thus the theoretically preferred choice when studying human language, but it is difficult to control for when it comes to finding the same conditions for all factors. Testing the significance of contributing factors is therefore aggravated due to a greater level of uncertainty.

Xu (2010) proposes that one way of making sure that patterns found in lab speech can be generalized for spontaneous speech is by comparing the results in read and spontaneous speech. This has been done, for example, in Lippus et al. (2013) for Estonian three-way quantity, where words with vocalic quantity and consonant clusters were studied based on spontaneous speech material. Their results showed that quantity characteristics generally followed the patters found in read speech.

The results presented in article [P2] that used spontaneous test material were also compared to available results from read speech (Eek 1974), albeit the latter were recorded from only one test subject. Consonants in Eek's study occurred in /ɑ-ɑ/ vocalic context, while consonants in article [P2] were studied in different vocalic contexts. Despite the differences between the two studies, the results from read speech and spontaneous speech were similar. The intrinsic durations of consonants in read speech were generally longer than in spontaneous speech, but in both speech conditions bilabials were longer than both alveolars and

velars. Moreover, quantity characteristics regarding duration ratios of length categories were similar in read and spontaneous speech. That indicates that in read speech sounds are better articulated than in spontaneous speech, but the intrinsic properties of segments and quantity characteristics are relatively stable even in spontaneous speech, which is characterized by richer prosody and coarticulation phenomena.

When taking the variable segmental context into account, as done in publications [P1] and [P3], the former of which used repetitions of words (articulatory data) and the latter spontaneous data (acoustic data), the results showed a similar direction in the variation of quantity manifestations. In both studies, the coarticulatory effects were greater when the stressed syllables of disyllabic feet contained low vowels compared to high vowels. In those cases, differences between Q2 and Q3 were often ruled out. Thus, it could be argued that regardless of the speech situation, the durational aspects of three-way quantity are stable enough to be realized but are greatly influenced by the underlying segmental context.

4.6.2. Classical and Bayesian statistics

In this thesis, two approaches to statistical analysis are used: traditional (also called classical or frequentist) and Bayesian statistics. The data in publications [P1], [P2] and [P4] are analyzed using traditional mixed-effects models (also referred to as multilevel, hierarchical or nested models) and article [P3] uses Bayesian generalized mixed-effects models. Multilevel models are used to analyze data where individual observations belong to clusters. Since both classical and Bayesian statistics were used in the thesis, this section aims at bringing out the main differences, as well as benefits and disadvantages of the two approaches.

Using Bayesian methods in linguistics or the social sciences (cf. Lynch 2007 for Bayesian statistics in the social sciences) is not widespread due to its complicated nature and lack of user-friendly software programs. As an example from linguistics, a Bayesian approach to statistics was taken to study the timing aspects of Finnish quantity (O'Dell 2003) using Markov Chain Monte Carlo technique in WinBUGS (Spiegelhalter et al. 2003). Estonian quantity has been studied with traditional frequentist methods only. Non-parametric Bayesian models have been used for computational morphology in the work of Kairit Sirts (2015). Recent developments in software packages for Bayesian multilevel modelling have made it accessible for a wider range of users (cf. Mai, Zhang 2018 for an overview and comparison of different packages). For example, a tutorial for implementing Bayesian methods in phonetic studies has been provided by Shravan Vasishth et al. (2018); the statistical analysis in publication [P3] of this thesis was based on this tutorial. In addition, summary statistics can be computed with the sjstats package which, in addition to traditional models, also deals with Bayesian models (Lüdecke 2017).

The major difference between frequentist and Bayesian statistics lies in the interpretation of parameters as fixed or random. In the view of classical statistics, an unknown quantity cannot be fixed and random at the same time, while an unknown value for fixed parameter does not necessarily mean that it is random. In Bayesian statistics, on the other hand, an unknown fixed parameter can be treated as random. This randomness is represented by a prior distribution, which is updated into a posterior distribution after seeing the data (McElreath 2016; Päll, Maiväli 2017).

In the case of traditional statistics, statistical inferences are made based on significance testing and reporting p-values which give the probability for the true null hypothesis (i.e., generally the hypothesis which says that there is no relationship between dependent and independent variables), which indicates the chances of being wrong in testing whether or not the event occurs. P-values and confidence intervals depend on sample size. Confidence intervals express the range of values within which the true value of a parameter is likely to be found when all instances could be measured (parameters are fixed, the data are random). Confidence intervals are not probability distributions – 95% confidence intervals show that in 95% of the cases (experiments, for example) the true value of the parameter lies in the range of the confidence intervals, while in 5% of the cases it does not. Thus, in a 1/20 chance level, the confidence interval does not include the true value.

The Bayesian approach does not use p-values; instead, it provides a posterior probability distribution that is a joint distribution of unknown parameters (expressed by prior distributions) and data (expressed by a likelihood function). More broadly, posterior distribution is a probability distribution of plausible values representing an effect, thus offering an informative quantitative summary of the effect (McElreath 2016; Stevens 2009; Vasishth et al. 2018; Päll, Maiväli 2017). The concept of credible intervals is used instead of confidence intervals. A 95% credible interval shows that the parameter value lies in the interval with 95% probability given the observed data (parameter values are random, data are fixed). This can be useful when one's aim is to describe complex relations between factors that would be difficult to calculate and interpret in the case of frequentist models with multiple interactions, as was the case in publication [P3]. In this study, it was of interest how and to what extent quantity and segmental quality interact with each other, rather than whether certain effects are present or absent. In publication [P3], using Bayesian methods turned out to be a good way of studying these complex interactions. In publication [P2], the durations of intervocalic consonants as a function of consonant quality and quantity were studied using traditional mixed-effects models. The results in the two studies were similar. A Bayesian approach was later used in publication [P3] since the effects from vocalic contexts were added to the interactions, which also narrowed down the number of tokens for each group.

In sum, applying Bayesian approach to statistics demands more thought but provides significant advantages over classical approach. It is more flexible than traditional methods, and it better handles smaller sample sizes. However, the

Bayesian alternative to statistics should be used with caution regarding subjectivity in choosing priors (Stan Development Team 2017b). Prior distributions reflect the beliefs of the parameter values, which can be based on previous results or expert knowledge. Thus, it could be argued that traditional methods in that sense are more objective than Bayesian methods. Choosing between classical and Bayesian approaches largely depends on the experiment, data and purposes of the study, or simply on the preferences of the researchers.

5. CONCLUSIONS

This thesis investigated the phonetic manifestations of the phonological three-way consonantal quantity systems in two Finno-Ugric languages, Estonian and Inari Saami. It had two main aims: first, to study the phonetic properties describing the three-way consonantal quantity at the articulatory and acoustic levels, and second, to investigate interactions between quantity and segmental context.

The articulatory characteristics of Estonian consonantal quantity were studied in a modern way by using electromagnetic articulography. The results showed that Estonian quantity does not have a linear three-way manifestation at the articulatory level. The three-way consonantal quantity was realized in some articulatory properties of gestures involved in producing the contrast, while in many cases Q1 and Q2 were opposed to Q3, or Q1 was opposed to Q2 and Q3. Most explicitly, the ternary distinction was reflected in the duration of the lip closing gesture for the intervocalic plosive /p/: lip closing gestures were longer as quantity increased. In addition, Q2 and Q3 differed in the duration and velocity of the tongue transition gesture for the vowels surrounding the consonant. The gesture was longer and slower in the case of Q3. Future research could deal with the articulatory patterns of quantity in Inari Saami as well.

As for the acoustic aspects, the results of this thesis showed that the clearest way to describe the three-way consonantal quantity in both Estonian and Inari Saami was the duration of intervocalic consonants. An increase in quantity degree was expressed by longer consonant duration. However, cross-linguistic differences appeared in the exact way in which different quantities were manifested. In Estonian, long geminates in read speech are 2 times longer than short consonants and overlong geminates are 1.5 times longer than long geminates (Eek 1974; Markus et al. 2013). In spontaneous speech (used in this thesis), Q2 geminates were 1.5 times longer on average than Q1 consonants, and Q3 geminates were 1.4 times longer than Q2 geminates. In Inari Saami, the differences in consonantal durations between different quantities were the opposite of those in Estonian: Q2 geminates were 1.5 times longer than Q1 consonants, while Q3 geminates were almost 2 times longer than Q2 geminates. This goes well with the term ‘half-long’ that has been used for Q2 geminates in older descriptions of Inari Saami quantity (Itkonen 1971; Sammallahti 1998).

The duration ratios expressing correlations between adjacent segments showed differences between foot structures. In Estonian, the duration of a vowel that was following a consonant with alternating quantity shortened when the consonantal quantity increased. This has also been shown in previous studies using read speech data (Eek 1974; Markus et al. 2013). The results of this dissertation confirmed that the durational relationships between segments also hold for a large set of test subjects and, moreover, are preserved in spontaneous speech. Thus, for describing three-way consonantal quantity in Estonian, comparing the durations of adjacent segments appears to be a relatively stable

characteristic. These results may lend support to the idea of Krull and Traunmüller (2003), who suggest that quantity is perceived by comparing the durations of segments in sequences. Different patterns were found in Inari Saami, where the durations of both vowels were negatively correlated with consonantal duration.

Differences between Estonian and Inari Saami could be due to the complexity of the quantity systems: Estonian has three degrees of quantity regarding vowels and consonants, while in Inari Saami three quantities are based on consonants only. Estonian uses F0 for distinguishing between Q1 and Q2 vs. Q3. However, it has been shown that in the perception of quantity in words with intervocalic plosive consonants, where the pitch cue is missing, the temporal structure of the word is sufficient for distinguishing between all quantity categories (Lippus, Pajusalu, Allik 2007, 2009). Whether this also holds for words with intervocalic sonorant consonants could be studied as well. The results of this thesis showed that fundamental frequency contours in Inari Saami disyllabic feet were roughly the same regardless of the foot structure. This coincides with findings from two other languages with the three-way consonantal quantity systems, Lule Saami (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014) and Livonian (Tuisk 2012). Future studies on the relations between F0 and duration in Inari Saami could elaborate on the role of F0 in the perception of quantity. While quantity effects on the fundamental frequency contours were small in Inari Saami, the intensity values appeared to be connected with quantity; the intensity of V1 increased and the intensity of V2 decreased when the quantity of the intervocalic consonant increased.

The second aim of the thesis was to provide an account for segmental variation in the realization of the three-way consonantal quantity contrast. The results showed complex relationships between segmental context and quantity at both articulatory and acoustic levels. The articulatory lip closing gesture showed the ternary distinction in stimuli with an /i-ɑ/ vocalic context indicating a smaller effect from the vowel /i/ in the stressed syllable, while quantity interacted with the low vowel /ɑ/ that has a stronger coarticulatory nature than the more constrained high vowel /i/. In the case of the acoustic manifestation of three-way quantity, there were also more overlaps of consonant durations in Q1 and Q2 or Q2 and Q3 when the preceding or the following vowel was /ɑ/ as opposed to high vowels. In addition, the duration ratios of quantity degrees were different for different consonants. The greatest differences between Q1 and Q2 were found for alveolars /t/ and /n/, and between Q2 and Q3 for /t/ and /k/. Q2 and Q3 overlapped for /n/. Both articulatory and acoustic results indicate that quantity manifestations are connected to lower-level microprosodic characteristics of segments.

In sum, the phonological three-way consonantal quantity systems in Estonian and Inari Saami exhibit differences in their phonetic manifestations. While the ternary quantity distinction is a foot level phenomenon in both languages and realized in the duration of the intervocalic consonant, the duration ratios of intervocalic consonants in different quantities and the ratios of the neighboring

segments are language-specific. In addition, the way in which Estonian and Inari Saami make use of the non-temporal characteristics of quantity also differ in the two languages, indicating the complexity and different prosodic developments of quantity systems. Moreover, the articulatory and acoustic properties found for the three-way consonantal quantity distinction in Estonian suggest that it is important to consider the effects of segmental context as quantity is not completely independent of lower level segmental characteristics while operating at a higher prosodic level. Future studies could investigate what the implications are from a perceptual point of view.

6. KOKKUVÕTE

Konsonandikeskne vältesüsteem eesti ja inarisaami keeles

Doktoritöös käsitletakse eesti ja inarisaami keele kolmese konsonandikvantiteedi ehk konsonandikeskse vältesüsteemi foneetilist realiseerumist nii artikulatoorsel kui ka akustilisel tasandil. Töö eesmärk on uurida, kuidas kolmene konsonandikeskne kvantiteedikontrast nendes kahes soome-ugri keeles avaldub ning mil määral on kvantiteet seotud segmentaalse konteksti ehk mikroprosoodilise varieerumisega.

Uurimisteema teeb huvitavaks fakt, et kolmene konsonandikvantiteet eksisteerib vaid mõningate keelte fonoloogilises süsteemis, eristades sõnade tähendusi ja vorme. Tavalisem on, et kvantiteediopositsioonide puhul on tegemist binaarse vastandusega, kus konsonandid võivad olla lühikesed või pikad. Viimaseid nimetatakse ka geminaatideks. Sellised keeled on näiteks soome (Suomi, Toivanen, Ylitalo 2008), ungari (Neuberger 2015), itaalia (Payne 2005), jaapani (Idemaru, Guion 2008) ja araabia keel (Issa 2015). Teadaolevalt esineb kolmest konsonandikeskset kvantiteedisüsteemi vaid soome-ugri keeltes, näiteks eesti keeles (Lehiste 2003), liivi keeles (Lehiste et al. 2008) ning mitmes saami keeles – inarisaamis (Bye, Sagulin, Toivonen 2009), põhjasaamis (Magga 1984), koltasaamis (McRobbie-Utasi 2007) ja Lule saamis (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014). Nendes keeltes kirjeldatakse konsonante kolme pikkuskategooriaga: lühike, pikk ja ülipikk. Mõne keele puhul on pikka ja ülipikka kategooriat nimetatud vastavalt ka poolpikkadeks ja pikkadeks geminaatideks või lühikesteks ja pikkadeks geminaatideks.

Eesti keeles esineb keerukas vältesüsteem, kus kolm pikkuskategooriat avalduvad nii vokaali- kui ka konsonandikeskselt. Inarisaami keeles on samuti kolm konsonandikeskset pikkuskategooriat, kuid rõhulise silbi vokaalid võivad olla kas lühikesed või pikad. Mõlemat keelt ühendab see, et geminaate on defineeritud kui konsonante, mis asuvad kahesilbilise kõnetakti rõhulise ja rõhuta silbi piiril. Seega kuulub osa geminaatkonsonandist rõhulise silbi koodasse ja osa rõhutu silbi algusesse. Eesti keeles on väldet foneetiliselt kirjeldatud just nende silpide kestussuhete kaudu, kasutades varieeruva vokaalikvantiteediga materjali. Geminaatkonsonantide puhul on selline lähenemine problemaatiline, kuna ei ole täpselt teada, kus asub silbipiir. See võib olla ka põhjus, miks konsonandikesksele osale on eesti keele vältesüsteemi käsitlevates uurimustes vähe tähelepanu pööratud. Inarisaami keele konsonandikvantiteedi foneetilist realiseerumist on uuritud kahes artiklis, mis keskenduvad kvantiteedi kestuslikele tunnustele (Bye, Sagulin, Toivonen 2009; Markus et al. 2013). Tulemused on olnud mõneti varieeruvad, mistõttu ei ole päris selge, kuidas kvantiteet erinevates jalastruktuurides realiseerub. Samuti ei ole teada, milline on sealjuures mittetemporaalsete tunnuste osakaal.

Sageli on öeldud, et kvantiteediopositsioonid on oma olemuselt maksimaalselt binaarsed ning ternaarsed süsteemid taanduvad samuti binaarsele tasemele (McRobbie-Utasi 2007). Kolmese konsonandikvantiteedi foneetilise olemuse

mõistmiseks on vaja seda kirjeldada erinevatest aspektidest, lähtudes erinevatest keeltest ja kontekstidest. Käesolevas doktoritöös käsitletakse eesti ja inarisaami keele ternaarsete konsonandikesksete kvantiteedisüsteemide foneetilist realiseerumist.

Töö esimeses pooles uuritakse, millised artikulatoorsed ja akustilised omadused kirjeldavad kolmest konsonandikvantiteeti, otsides vastuseid küsimustele: a) millised on eesti keele konsonandikvantiteedi artikulatoorsed tunnused ja kas artikulatoorsel tasandil esineb kolmene eristus; b) kuidas realiseerub akustiliselt eesti keele konsonandikvantiteet; millised on kvantiteedi temporaalsed tunnused ning kõrvuti asetsevate segmentide omavahelised suhted; c) kuidas realiseerub kolmene konsonandikeskne kvantiteedisüsteem inarisaami kahesilbilistes erineva struktuuriga sõnades; d) kuidas mõjutavad kõrvutiasetsevad segmendid üksteist inarisaami kahesilbilises kõnetaktis; e) milline on põhitooni ja intensiivsuse osa inarisaami kolmese konsonandikvantiteedi realiseerumisel?

Doktoritöö teises pooles käsitletakse segmentaalse konteksti ja välte omavahelisi seoseid. Kasutades eesti keele artikulatoorset ja akustilist materjali, püütakse leida vastuseid järgmistele küsimustele: a) kas ja kuidas mõjutab varieeruv segmentaalne kontekst välte artikulatoorset realiseerumist; b) kuidas realiseerub välde akustiliselt erineva hääldusko ha ja -viisiga vokaalidevaheliste konsonantide korral; c) mil määral ja viisil seostuvad akustilised vältetunnused konsonandi- ja vokaalikontekstiga?

Käesolev doktoritöö koosneb kuue peatükiga sissejuhatavast osast ja publikatsioonidest. Sissejuhatava osa esimene peatükk tutvustab töö uurimisvaldkonda ja -küsimusi ning annab ülevaate artiklites käsitletud teemadest ja töö autori panusest kaasautoritega publikatsioonide puhul. Teises peatükis esitatakse töö materjal ja metoodika. Sellest järgmises tutvustatakse doktoritööga seotud põhilisi mõisteid, millele järgneb ülevaade geminaatide foneetilistest omadustest binaarse kvantiteedisüsteemiga keeltes. Ühtlasi antakse põgus ülevaade kolmestest konsonandikesksetest kvantiteedisüsteemidest liivi, isuri ja saami keeles ning pikemalt kirjeldatakse eesti ja inarisaami keele vältesüsteeme. Neljandas peatükis esitatakse doktoritöö tulemused ja arutelu ning peamised järeldused võetakse kokku viiendas peatükis. Kuuendas peatükis esitatakse eestikeelne kokkuvõte ning seejärel kõik töös kasutatud viited.

Materjal ja meetodid

Artikulatsioonikatse materjal artiklis [P1] on salvestatud neljalt eesti keelt emakeelena kõnelevalt keelejuhilt (kahelt mees- ja kahelt naiskeelejuhilt vanuses 34–57, keskmine vanus 41). Lindistused on tehtud Helsingi Ülikoolis elektromagnetilise artikulograafiga (EMA, AG500, Carstens Medizinelektronik). Lindistati keele, lõua ja huulte (üla- ja alahuule) liikumist ning paralleelselt salvestati ka akustiline materjal. Stiimuliteks olid kahesilbilised CVpV-struktuuriga sõnad, mis sisaldasid kõiki eesti keeles võimalikke kvantiteedikombinatsioone, kokku 28 stiimulit (vt tabel 1). Sõnaalguline konsonant oli kas /p/ või /t/ ning vokaalidevaheline konsonant /p/ esines /ɑ-i/ ja /i-ɑ/-kontekstis. Keele-

juhid kordasid iga stiimulit umbes kümme korda järjest (ilma pausideta) ning stiimuli kohta kasutati analüüsiks 118–129 sõna. Analüüsi jaoks märgendati stiimulites kõigi segmentide piirid kõneanalüüsiprogrammiga Praat (Boersma, Weenink 2014). Artikulatoorsete liigutuste piirid märgendati programmiga MATLAB.

Akustiline eesti keele materjal publikatsioonides [P2] ja [P3] on kogutud Tartu Ülikooli eesti keele spontaanse kõne foneetilisest korpusest (Lippus et al. 2006) märtsis 2017. Sel ajal sisaldas korpus 79 tundi segmenteeritud ja märgendatud lindistusi, mis olid kogutud aastatel 2006–2017. Analüüsiks kasutati lindistusi 40 meeskõnelejalt ja 34 naiskõnelejalt. Meeste vanus jäi vahemikku 20–85 aastat (keskmine vanus oli 37,8 aastat) ja naiste vanus oli vahemikus 20–78 aastat (keskmine vanus 37,1 aastat). Kõik keelejuhid rääkisid eesti ühiskeelt. Korpusest koguti erineva struktuuriga kahesilbilisi sõnu, kus rõhulise (V1) ja rõhuta silbi (V2) vokaalid olid alati lühikesed ning vokaalidevaheline konsonant (C2) oli kas lühike (Q1), pikk (Q2) või ülipikk (Q3) (vt näiteid tabelis 2). Analüüsitud konsonandid olid /p, t, k, s, m, n, l/ ning ümbritsevad vokaalid lühikesed monoftongid /i, y, u, e, ø, ɤ, o, ɑ/ esimeses silbis ja /i, u, e, o, ɑ/ teises silbis. Kõigi segmentide kestused sõnas mõõdeti Praati skriptiga.

Publikatsioonis [P4] analüüsitud akustiline inarisaami andmestik on lindistatud 2013. aastal Inaris, kasutades diktofoni Edirol R-09. Ainestik on kogutud neljalt meeskeelejuhilt vanuses 62, 68, 76 ja 77 (keskmine vanus 70,8). Kaks keelejuhti on sündinud Inaris, ühe sünnikohaks on Syysjärvi ning ühel Ylivieska. Lisaks oma emakeelele kõnelevad kõik katseisikud soome keelt, kolm neist oskab ka põhjasaami keelt. Helisalvestised sisaldasid loetud lauseid, kuhu olid fraasikesksesse ja fraasilõpulisse positsiooni paigutatud kahesilbilised lühikese, poolpika ja pika vokaalidevahelise konsonandiga testsõnad (vt tabel 3). Esisilbi vokaal oli fonoloogiliselt lühike või pikk monoftong või diftong ning järgsilbi vokaal alati lühike. Analüüsiks mõõdeti kõigi segmentide kestused millisekundites, põhitooni mõõdeti hertsides esisilbi vokaali algusest kuni teise silbi vokaali lõpuni 20-st üksteisest võrdsel kaugusel olevast punktist. Samuti mõõdeti vokaalide ja nendevahelise konsonandi keskmist intensiivsust detsibellides. Kokku kasutati segmendikestuste analüüsiks 1463 sõna, põhitooni ja intensiivsuse analüüsiks vastavalt 1043 ja 597 sõna. Testsõnades märgendati kõigi segmentide piirid programmiga Praat (Boersma, Weenink 2014).

Statistiline andmeanalüüs

Kõigis artiklites tehti statistiline andmeanalüüs programmiga R (R Development Core Team 2014). Artiklites [P1], [P2] ja [P4] kasutati traditsioonilisi segamudeleid (Bates et al. 2014) ning artiklis [P3] Bayesi statistikal põhinevaid segamudeleid (Bürkner 2017). Bayesi statistikas puuduvad tõenäosused, millele on üles ehitatud traditsioonilise ehk sagedusliku statistika põhimõtted. Järeldusi tehakse posterioorse tõenäosusjaotuse põhjal, mis on kombineeritud tõepärafunktsioonist ja aprioorsest tõenäosusjaotusest (McElreath 2016; Päll, Maiväli 2017). Statistilised segamudelid hõlmavad populatsiooni piires mittevarieeruvaid

faktoreid ning varieeruvaid (juhuslikke) faktoreid. Kõigis kolmes publikatsioonis rakendatud mudelites arvestati juhuslike faktoritena keelejuhtide ja testsõnadega. Faktorite tasemete edasiseks paariviisiliseks võrdlemiseks kasutati Tukey HSD testi.

Publikatsioonis [P1] hinnati sagedusliku statistika põhimõtetel koostatud segamudelite abil, kas ja mil määral avaldub eesti keele konsonandikeskne kolmevältesüsteem artikulatoorsete liigutuste kaudu. Sealjuures arvestati ka varieeruvat segmentaalset konteksti. Kuna eesmärk oli kirjeldada vältega seotud varieerumist, siis iga artikulatoorse tunnuse jaoks (huulte sulgemise kestus, ulatus, tippkiirus jne) koostati ühesugune mudel, selle asemel, et välja jätta neid faktoreid, mis statistiliselt olulised ei olnud. Statistilist olulisust testiti paariviisiliselt.

Artiklites [P2] ja [P4] kasutati samuti traditsioonilisi segamudeleid, kuid faktorite olulisust uuritava tunnuse varieerumisel testiti ükshaaval, jättes välja need faktorid, mis statistiliselt olulised ei olnud. Publikatsioonis [P2] hinnati, kas ja kuidas on vokaalidevahelise konsonandi kvaliteet oluline kolmese konsonandikvantiteedi temporaalsel realiseerumisel. Artiklis [P4] testiti välte ja fraasipositsiooni ning nende interaktsioonide osa kahesilbilise jala iga segmendi kestuse ning põhitooni ja intensiivsuse väärtuste varieerumisel.

Publikatsioonis [P3] rakendati segamudeleid Bayesi statistika põhimõtetel. Selline lähenemine valiti mitmel põhjusel: Bayesi statistika ei sõltu andmete hulgast nii nagu traditsioonilise statistika tõenäosuslikud hinnangud, keerukamate mudelitega töötamine on paindlikum, posterioorse tõenäosusjaotuse kaudu saab tulemusi otsesemalt ja kergemini tõlgendada. Samuti on võimalik mudelisse lisada eelteadmisi (aprioorne tõenäosusjaotus). Uurimuse eesmärk publikatsioonis [P3] oli kirjeldada keerukamaid interaktsioone konsonandikvaliteedi, -kvantiteedi ja vokaalikonteksti vahel spontaankõnest kogutud materjali põhjal, kus esineb palju varieerumist ning kus ei olnud võimalik andmestikku täielikult kontrollida. Eesmärk oli pigem kirjeldada välte ja segmentaalse konteksti omavahelisi suhteid kui testida ühe või teise faktori statistilist olulisust. Bayesi statistika posterioorne tõenäosusjaotus võimaldas näha, millised on mudeli järgi konsonantide keskmised kestused eri kontekstides ja väldetes ning millisesse vahemikku jäävad parameetri väärtused 95% tõenäosusega.

Tulemused

Artiklis [P1] vaadeldi, millised on kolmese konsonandikvantiteedi artikulatoorsed tunnused eesti keeles. Uuriti, kas huulte sulgemise ja avamise ning keele liikumise kinemaatiliste tunnuste puhul (kestus, ulatus ja tippkiirus) on näha vastavat kolmest mustrit.

Tulemused näitasid varieerumist, mis sõltus vokaali ja konsonandi kontekstist. Peamiselt avaldus kolme välte kontrast huulte sulgemisliigutuse kestuse kaudu, mis oli kõrgema vältega sõnades pikem. Küll aga esines selline kolmene eristus ainult /i-ɑ/-kontekstiga sõnades. Sarnane tendents tuli välja ka huulte sulgemisliigutuse ulatuse puhul, mis oli ulatuslikum kõrgema vältega sõnades,

kuid teine ja kolmas välde omavahel ei eristunud. Huulte sulgemisliigutuse tippkiirus ei olnud sealjuures välteti erinev. Huulte avamisliigutuse kinemaatilised tunnused konsonandikvantiteedist ei sõltunud, kuid Q3 vokaalikvantiteedi korral oli huulte avamisliigutus kestuselt lühem ning väiksema ulatusega kui Q1 ja Q2 puhul. Sellist tulemust võib seletada teise silbi vokaali kompensatoorse varieerumisega, mis sõltub esimesest silbist. Teise silbi vokaal on pikem pärast lühikest esimest silpi ja lühem pärast pikka või ülipikka esimest silpi (Lehiste 2003). Seega võib olla, et huulte avamiseks jääb vähem aega, kui teise silbi vokaal on lühem.

Eesti keele sonorante uurides on Arvo Eek (1970a, 1970b, 1971a, 1971b, 1971c) leidnud, et ülipikad konsonandid moodustatakse kiiremate artikulatoorsete liigutustega kui lühikesed ja pikad konsonandid, viimased kaks eristuvad liigutuste kestuse poolest. Erinevused uurimuste vahel võivad tulla sellest, et Eek kasutas materjali, kus segmentaalne kontekst ei varieerunud. Samuti olid uurimismeetodid erinevad. Kui Eek filmis huulte liigutusi, kasutas palatograafiat, röntgenit jms, siis publikatsioonis [P1] tehti mõõtmised modernse ja küllaltki täpse elektromagnetilise artikulograafiga. Muudes binaarse kvantiteedioppositsiooniga keeltes on samuti näidatud, et geminaatide moodustamisel on huulte sulgemisliigutused pikemad ja ulatuslikumad kui lühikeste konsonantide moodustamisel (Löfqvist 2007; Ridouane 2007; Šimko, O'Dell, Vainio 2014; Zeroual, Hoole, Gafos 2008).

Publikatsioonis [P1] uuriti ka konsonandikvantiteedi seost konsonanti ümbritsevate vokaalide hääldamisega. Tulemused näitasid, et keele liikumine üleminekul esimeselt vokaalilt teisele oli pikem ja aeglasem siis, kui vokaalidevaheline konsonant oli pikem. Ülipikk välde eristus lühikesest ja pikast. Samuti algas suurema konsonandikeskse vältega sõnades keele liikumine huulte sulgemisliigutuse suhtes hiljem. Kolmene välteeristus tuli välja /t/-algulistes sõnades, kus bilabiaal esines /ɑ-i/-kontekstis. Kui esisilbi vokaali kvantiteet suurenes, siis algas keele liikumine teise silbi vokaalile huulte sulgemisliigutuse suhtes aga varem. Ka soome keele lühikeste ja geminaatkonsonantide puhul on leitud, et geminaatidega sõnades algab keele liikumine hiljem kui üksikkonsonantidega sõnades (Šimko, O'Dell, Vainio 2014).

Publikatsioonid [P2], [P3] ja [P4] keskendusid kolmese konsonandikvantiteedi akustiliste omaduste uurimisele. Artiklis [P1] käsitleti konsonantide akustilist kestust põgusalt ning näidati, et vokaalidevahelise konsonandi kestus on kõigis kolmes vältes selgelt erinev. Kestuserinevused olid väiksemad, kui muutus nii vokaali kui ka konsonandi pikkus. Publikatsioonis [P2] uuriti konsonandikvantiteedi kestusega seotud tunnuseid sõltuvalt konsonandi kvaliteedist ning artiklis [P3] vaadeldi välte realiseerumist varieeruva konsonandi- ja vokaalikonteksti puhul.

Publikatsioonides [P2] ja [P3] käsitletud eesti keele pikad geminaadid olid lühikestest konsonantidest 1,5 korda pikemad ning ülipikad geminaadid olid pikkadest geminaatidest 1,4 korda pikemad. Varasemates uurimustes on leitud, et loetud kõnes on pikkade geminaatide ja lühikeste konsonantide suhe 2 ning ülipikkade ja pikkade geminaatide suhe on 1,4 (Eek 1974). Kõnematerjal

publikatsioonides [P2] ja [P3] on võetud spontaansest kõnest, mis seletab väiksemaid väldetevahelisi erinevusi kui loetud kõnes. Välteerinevused avaldusid ka teise silbi vokaali kestuses, mis oli pärast pikka ja ülipikka geminaati lühem kui pärast lühikest konsonanti. Seega võib öelda, et kolmest konsonandikeskset kvantiteedisüsteemi kirjeldavate segmentide kestussuhted on stabiilsed, olles säilinud ka spontaanses kõnes. See tulemus võib toetada Krulli ja Traunmülleri (2003) ideed, et välte tajumisel võrreldakse omavahel järjendites olevaid segmentide kestusi.

Artiklis [P4] käsitleti konsonantide kolmese kvantiteedikontrasti realiseerumist inarisaami kahesilbilistes sõnades. Keskenduti kvantiteedi akustilistele tunnustele, uurides, kuidas realiseerub konsonantide kolmene kvantiteedisüsteem nii fonoloogiliselt lühikeste kui ka pikkade esisilbi vokaalidega sõnastruktuurides. Samuti vaadeldi, kuidas mõjutavad üksteist kõrvutiasetsevad segmendid ning milline on põhitooni ja intensiivsuse osa välte realiseerumisel.

Tulemused näitasid, et inarisaami konsonandid on lühikesed, poolpikad või pikad pärast lühikest rõhulise silbi vokaali. Poolpikad geminaadid olid lühikestest konsonantidest 1,5 korda pikemad ning pikad geminaadid olid 1,8 korda pikemad kui poolpikad geminaadid. Kui esisilbi vokaal oli pikk, siis sellele järgnev konsonant oli lühike või poolpikk. Sellistes sõnades olid poolpikad geminaadid 1,7 korda pikemad kui lühikesed konsonandid. Kahesilbilises kõnetaktis olid segmendid omavahel seotud, mõjutades üksteist kompensatoorselt: 1) lühikese esisilbi vokaaliga sõnades konsonandikvantiteedi suurenedes konsonanti ümbritsevate vokaalide kestused vastavalt lühenesid; 2) pika esisilbi vokaaliga sõnades kompenseeris lühem rõhutu silbi vokaal samuti eelneva vokaali ja konsonandi pikemat kestust. Teise silbi vokaal pikenes vaid juhul, kui rõhuline vokaal oli lühike ning sellele järgnev konsonant oli kas lühike või poolpikk. Kuna kahesilbilises jalas on segmendid omavahel korrelatsioonis, võib öelda, et inarisaami konsonantide kolmene kvantiteedieristus on sarnaselt eesti keelega jalataseme nähtus. Publikatsiooni [P4] tulemused kattusid varem (Bye, Sagulin, Toivonen 2009) leituga lühikeste esisilbi vokaalide osas, kuid osal keelejuhtidel avaldus varasemate andmete põhjal konsonantide kolmene kvantiteedieristus ka pärast pikka esisilbi vokaali. Erinevused kahe uurimuse vahel võivad tuleneda keelejuhtide erinevast murdetaustast.

Artiklis [P4] uuriti ka põhitooni ja intensiivsuse rolli inarisaami kvantiteedi realiseerumisel. Põhitoonikontuuride analüüsil selgus, et inarisaamis on põhitoon kvantiteedikontrasti sekundaarne tunnus. Erinevalt eesti keelest, kus eri struktuuridega sõnadele on omane teatud toonikontuur ning põhitoonil on vältetajus oluline osa just teise ja kolmanda välte eristamisel, oli inarisaami eri struktuuriga sõnades põhitoonikontuur enam-vähem sama. Põhitoon pööras langusele kõigis sõnades peaaegu et samas kohas ning ka selle ulatus, st maksimum- ja miinimumväärtuste vahe kogu sõna jooksul palju ei varieerunud. Põhitooni langust kirjeldav kaldenurk oli lühikese ja poolpika konsonandiga sõnades järsem, pika konsonandiga sõnades aga lamedam, mida põhjustas nende sõnade teise silbi vokaali kõrgem põhitooniväärtus. Kui temporaalsete tunnuste olulisust välte realiseerumisel näitas kahesilbilises kõnetaktis olevate segmentide

omavaheline vastastikune mõju, püüd hoida eri struktuuriga sõnad sarnase kestusega, siis tooniliikumist välde eriti ei mõjutanud. Põhitoonil on seega kvantiteedikontrasti avaldumisel sekundaarne roll, mis on seotud primaarsete kestuslike tunnustega.

Publikatsioonis [P4] leiti, et ka intensiivsus on inarisaami kolmese kvantiteedikontrasti sekundaarne tunnus. Vokaalidevahelise konsonandi kvantiteedi suurenedes suurenes ka rõhulise silbi vokaali intensiivsus, kuid rõhutu silbi vokaali intensiivsus vähenes. Konsonandi enda intensiivsuse väärtused olid aga eri väldetes muutumatud. Sarnased tulemused on saadud ka Lule saami keele kohta, kus eksisteerib samuti konsonantide kolmene kvantiteedieristus (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014). Kuna välteeristus realiseerub vokaalidevahelise konsonandi kestuserinevuste kaudu, siis see, et konsonandi intensiivsus vältest ei sõltu, näitab intensiivsuse sekundaarset rolli kvantiteedikontrasti realiseerumisel. Kestuslike tunnuste ja intensiivsuse seostele viitab asjaolu, et konsonanti ümbritsevate vokaalide intensiivsus muutub seoses konsonandikvantiteediga.

Segmentaalse konteksti ja välte interaktsioonid

Publikatsioonides [P1], [P2] ja [P3] käsitleti konsonandikvantiteedi artikulatsiooni ja akustikat, arvestades varieeruvat segmentaalset konteksti.

Artiklis [P1] näidati, et kuigi mõningate häälduslіigutuste puhul kolmene kvantiteedieristus artikulatoorsel tasandil avaldus, ei esinenud siiski üleüldist mustrit, mis oleks kehtinud kõigi artiklis uuritud segmentaalsete kontekstide puhul. Varieerumine sõltus sõnaalgulise konsonandi (/t/ või /p/) või bilabiaali /p/ ümbritsevate vokaalide kontekstist (/i-ɑ/ või /ɑ-i/). Kõige selgem kolmene eristus tuli välja huulte sulgemisliigutuse kestuse puhul /i-ɑ/-kontekstis, kus huulte sulgemine võttis kauem aega, kui vokaalidevaheline konsonant oli pikem. /ɑ-i/-konteksti korral oli näha esimeses silbis oleva madala vokaali /ɑ/ suuremat interaktsiooni kvantiteedi ja sõnaalgulise konsonandiga. /t/-algulistes sõnades erinesid esimene ja teine välde kolmandast, kuid /p/-algulistes sõnades erines esimene välde teisest ja kolmandast. Ka üleminekul esimeselt vokaalilt teisele oli kontekstist sõltuvat keele liigutuste varieerumist. Kolmene eristus avaldus /t/-algulistes /ɑ-i/-kontekstiga stiimulites, kus üleminek oli seda pikem, mida suurem oli vokaalidevahelise konsonandi või rõhulise silbi vokaali välde. Samas oli /p/-algulistes /ɑ-i/-kontekstiga stiimulites kolme välte eristajaks keele liikumise tippkiirus, mis suurema konsonandikvantiteediga sõnades oli aeglasem. Kokkuvõtlikult näitasid artikli [P1] tulemused, et seosed kvantiteedi ja häälikute kvaliteedi vahel on küllaltki keerulised ning kvantiteediga seotud häälduslіigutuste kinemaatilistes omadustes selgeid kolmeseid mustreid välja tuua ei saa.

Akustilised tulemused publikatsioonides [P2] ja [P3] kinnitasid, et kolmese konsonandikvantiteedi realiseerumine sõltub konsonandi enda omadustest ning koartikulatsioonist ümbritsevate vokaalidega. Obstruendid olid kõigis kolmes vältes alati pikemad kui sonorandid; bilabiaalid olid pikemad kui alveolaarid ja

velaarid. Kui teises ja kolmandas vältes olid obstruentide omakestused rohkem ühtlustunud, siis sonorandid eristusid üksteisest enam. Teine ja kolmas välde kattusid /p/ ja /s/-i puhul. Interaktsioonid ümbritsevate vokaalidega näitasid veelgi enam kattuvusi teise- ja kolmandavälteliste sonorantide puhul, mis esinesid madalate ja keskvokaalide naabruses.

Kokkuvõte

Doktoritöös uuriti ternaarsete konsonandikesksete kvantiteedisüsteemide foneetilist realiseerumist kahes soome-ugri keeles – eesti keeles ja inarisaami keeles. Varasemad uurimused on näidanud, et eri keelte kvantiteedisüsteemid on mõnevõrra erinevad ning fonoloogilise kvantiteedi foneetilise olemuse mõistmiseks tuleks uurida seda lähtuvalt erinevatest aspektidest. Väitekirja eesmärk oli kirjeldada kolmeseid süsteeme erinevatel foneetilistel tasanditel, erinevates keeltes ja varieeruvas kontekstis. Doktoritöös käsitletud teemad olid jagatud kaheks suuremaks uurimisküsimuseks: a) kuidas realiseerub kolmene konsonandikeskne kvantiteedisüsteem artikulatoorsel ja akustilisel tasandil; b) milline on sealjuures segmentaalse konteksti osakaal?

Esimese suurema teema juures vaadeldi eesti keele geminaatkonsonantide artikulatsiooni ning nii eesti kui ka inarisaami geminaatide akustikat. Artiklis [P1] esitatud eesti keele geminaatide artikulatoorne analüüs põhineb elektromagnetilise artikulograafiga kogutud andmetel. Uuriti vokaalidevahelise bilabiaali /p/ artikulatsiooni eri väldetes ning eri kontekstides. Tulemused mõnevõrra sarnanesid varem leituga eesti keele sonorantide kohta: välteerinevused avaldusid häälduslіigutuste kinemaatiliste tunnuste (liigutuste kestuse, ulatuse ja tippkiiruse) kaudu keerukal ja mittelineaarsel viisil. Kõige selgem kolmene kvantiteedieristus avaldus huulte sulgemisliigutuse kestuses, mis suurema välte puhul oli vastavalt pikem. Teine ja kolmas välde erinesid ka selle poolest, et üleminekul esimeselt vokaalilt teisele oli keele liikumine pikema kestusega ning aeglasem siis, kui vokaalidevaheline konsonant oli kolmandas vältes. Esimese ja teise välte korral oli keele liikumine kiirem ning üleminek esimeselt vokaalilt teisele oli kestuselt lühem. Samuti uuriti, kuidas on artikulaatorite liigutused omavahel koordineeritud: millal toimub huulte sulgemisliigutus vokaalidevahelise bilabiaali hääldamiseks ning millal hakkab keel huulte sulgemisliigutuse suhtes liikuma teise silbi vokaali hääldamiseks. Tulemused näitasid, et keele liikumine algas hiljem, kui vokaalidevaheline konsonant oli kõrgemas vältes, ning varem, kui esimese silbi vokaal oli kõrgemas vältes. Kolmene välteeristus tuli välja /t/-algulistes sõnades, kus bilabiaal esines /ɑ-i/-vokaalikontekstis.

Akustiliselt eristas kolme konsonandikeskset pikkuskategooriat nii eesti kui ka inarisaami keeles konsonandi kestus, mis välte suurenedes pikenes. Keeltevahelised erinevused ilmnesid kategooriate kestussuhetes. Varasemad uurimused on näidanud, et eesti keele loetud kõnes on Q2 geminaadid 2 korda pikemad kui Q1 konsonandid ning Q3 geminaadid on 1,5 korda pikemad kui Q2 geminaadid (Eek 1974; Markus *et al.* 2013). Eesti spontaankõnes, mida selles doktoritöös uurimismaterjalina kasutati, olid need suhted väiksemad: Q2 geminaadid olid

keskmiselt 1,5 korda pikemad kui Q1 konsonandid ning Q3 geminaadid olid 1,4 korda pikemad kui Q2 geminaadid. Inarisaami keeles olid vastavad kestussuhted eesti keelega võrreldes justkui ümber pööratud: Q2 geminaadid olid 1,5 korda pikemad kui Q1 konsonandid ja Q3 geminaadid peaaegu 2 korda pikemad kui Q2 geminaadid.

Artikli [P4] analüüsist selgus, et inarisaami konsonantide kolmene kvantiteedieristus realiseerus kõige selgemalt kahesilbilistes sõnades, kus rõhulise silbi vokaal oli lühike. Pika vokaaliga sõnades Q2 ja Q3 geminaadid kestuselt ei erinenud, kuid samas tuli sellistes sõnades kolmene eristus välja konsonanti ümbritsevate vokaalide kestuste kaudu. Jalas olevad segmendid olid omavahel vastastikku seotud: välte suurenedes vokaalidevahelise konsonandi kestus pikenes, samal ajal aga lühenesid ümbritsevate vokaalide kestused. Samasugust seost konsonandikvantiteedi ja mõlema vokaali vahel võib leida ka Lule saami keelest (Fangel-Gustavson, Ridouane, Morén-Duolljá 2014). Eesti keeles esineb selline negatiivne korrelatsioon ainult teise silbi vokaaliga, mis on Q3 puhul lühem kui Q1 ja Q2 puhul (Eek 1974; Markus *et al.* 2013). Ka käesolevas doktoritöös kasutatud spontaanse kõne materjalis, mis pärines suuremalt hulgalt keelejuhtidelt, oli teise silbi vokaal pärast Q3 geminaati selgelt lühem, mis näitab, et kolmese konsonandikvantiteedi realiseerumisel on segmentide omavahelised kestussuhted stabiilsed nii loetud kui ka spontaanses kõnes.

Erinevused eesti ja inarisaami konsonandikeskse kvantiteedisüsteemi realiseerumisel tulevad välja ka põhitooni ja intensiivsuse kasutamisel. Eesti keeles on leitud, et põhitoon eristab Q1 ja Q2 *vs.* Q3 vokaalikeskse vältega sõnades (Lehiste 2003). Tajukatsed on aga näidanud, et kui välteeristus avaldub klusiilikeskselt ning põhitoonitunnus seega puudub, piisab kõigi kolme välte eristamiseks kestuslikest tunnustest (Lippus, Pajusalu, Allik 2009). Intensiivsuse mõõtmisel on saadud erinevaid tulemusi: on leitud, et intensiivsus eristab Q3 teistest väldetest (Eek, Meister 1997; Krull 2001) või siis ei ole sellel märkimisväärset rolli välte realiseerumisel (Kalvik, Mihkla 2010). Põhitooni ja intensiivsuse olulisust inarisaami konsonandikvantiteedi kirjeldamisel uuriti artiklis [P4]. Andmete akustiline analüüs näitas, et põhitoonikontuurid eri struktuuriga kahesilbilistes sõnades märkimisväärselt ei varieerunud. Põhitoon hakkas langema enam-vähem samas kohas ning kvantiteet ei mõjutanud ka selle ulatust. Küll aga erines pika konsonandiga sõnades põhitooni langust kirjeldav kalle lühikese ja poolpika konsonandiga sõnade omast, mis oli viimaste puhul järsem. Edasised tajukatsed võiksid anda rohkem informatsiooni põhitooni olulisuse kohta inarisaami konsonandikvantiteedi tajumisel. Intensiivsust võiks pidada inarisaami kvantiteedi sekundaarseks tunnuseks, kuna väldet kandva vokaalidevahelise konsonandi intensiivsus erinevas vältes ei muutunud. Samas aga mõjutas kvantiteet nii esi- kui ka järgsilpide vokaalide intensiivsust, mis konsonandikvantiteedi suurenedes rõhulise vokaali puhul suurenes ning rõhutu vokaali puhul vähenes.

Doktoritöö teises pooles käsitleti eesti keele kolmese konsonandikvantiteedi realiseerumist sõltuvalt segmentaalsest kontekstist. Tulemused näitasid sarnaseid tendentse nii artikulatoorsel kui ka akustilisel tasandil. Kinemaatiliste tunnuste

puhul võis näha kolmest süsteemi, mis kõige selgemini avaldus liigutuste kestuses. Sõltuvalt kontekstist tuli välja kas teise ja kolmanda välte vastandus esimesega või esimese ja teise välte vastandus kolmandaga. Huulte sulgemisliigutuse korral esines kolmene välteeristus /i-ɑ/-kontekstis, mis viitab sellele, et kõrge vokaal /i/ ei ole vältega nii tugevas seoses kui rohkem avatud madal vokaal /ɑ/. Keele liikumisel esimeselt vokaalilt teisele võis aga näha kolmest eristust siis, kui sõna algas konsonandiga /t/ ning bilabiaal /p/ oli /ɑ-i/-kontekstis.

Akustiliste andmete analüüsist artiklis [P3] selgus samuti, et kattuvusi erinevate vältekategooriate vahel põhjustas see, kui rõhulises silbis oli madal vokaal /ɑ/. Enam oli kattuvusi just sonorantide puhul, millele eelnesid kas madalad või keskkõrged vokaalid. Artikli [P2] tulemused näitasid ka, et geminеeruva konsonandi moodustuskohast ja -viisist tingituna realiseerusid väldetevahelised kestussuhted erinevalt. Suurimad erinevused Q1 ja Q2 konsonantide vahel esinesid /t/ ja /n/ puhul ning väikseimad /l/ ja /m/ korral. Q2 ja Q3 erinesid kõige enam konsonantide /k/ ja /m/ korral ning peaaegu kattusid konsonantide /n/, /p/ ja /s/ puhul.

Konsonantide kolmene kvantiteedieristus eesti ja inarisaami keeles on jalataseme nähtus, mis avaldub mõlemas keeles vokaalidevahelise konsonandi kestuses, kuid pikkuskategooriate omavahelised kestussuhted ning ümbritsevate vokaalide ja vokaalidevahelise konsonandi suhted on nendes keeltes erinevad. Samuti kasutatakse välte realiseerimisel erinevalt mittetemporaalseid komponente – põhitooni ja intensiivsust. Lisaks selgus doktoritöös, et välte kirjeldamisel on oluline arvestada segmentaalsest kontekstist tulenevate iseärasustega, mis põhjustavad küllaltki suurt varieerumist.

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Teenistuskäik

2017–2019	Tartu Ülikool, Humanitaarteaduste ja kunstide valdkond, eesti ja üldkeeleteaduse instituut, eesti ja soome-ugri keeleteaduse nooremteadur

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