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The acoustic features and perception of the Estonian quantity system

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FOREWORD

One day, about ten years ago, when I was a second year student looking for a topic for my BA thesis, I was walking on the stairs of the Faculty of Philosophy building in Lossi Street when I bumped into professors Jaan Ross and Karl Pajusalu. They both insisted that I chose a topic in phonetics. So I did, and I have never regretted.

To be honest, I never wanted to study the Estonian quantity. Most of the research on Estonian phonetics has focused on the quantity system while there are so many aspects that we know nothing about. However, after a while I realized that no matter which phonetic feature of Estonian you study, you cannot avoid the quantity system. So I decided to first study the quantity system itself and then, keeping the quantity system in mind, I could move on to other topics.

I am very glad I bumped into Jaan and Karl that day, and I did choose phonetics. During my studies I have bumped into many inspiring people, whom I would like to thank. First of all I would like to thank my supervisor Professor Karl Pajusalu, and professors Jüri Allik and Jaan Ross, who have all given me useful advice whenever I have needed it. I had very inspiring discussions with late Professor Ilse Lehiste and Arvo Eek, the grand old Estonian prosodists. I am very grateful that I could meet them and I am sorry that they cannot read my thesis. I would like to thank my colleagues at the phonetics lab, especially Pire Teras and Eva Liina Asu, who have helped me in many different ways. I thank Cameron Robert Rule and Virve Vihman who have proof-read my English, and Ellen Niit, who has proof-read my Estonian in this thesis. I would also like to thank the reviewers, Professor Stefan Werner and Meelis Mihkla for commenting my thesis.

During my doctoral studies I have received financial support from the Graduate School of Linguistics and Language Technology, the Graduate School of Linguistics, Philosophy and Semiotics, the Target Financed Research Programme "Phonetic, phonological, and morphophonological regularities of Finno-Ugric languages" (SF0180076s08), Estonian Science Foundation grants No. 5812 and 7904, the National Programme for Estonian Language Technology project "Phonetic Corpus of Estonian Spontaneous Speech", and the Estonian Fond of the Alfred Kordelin's Foundation.

Half of the papers in this thesis deal with the perception of Estonian quantity and this could not have been done without the test subjects. I am very grateful to everybody who volunteered to participate in the tests. The other half of the papers in this thesis uses the data from the Phonetic Corpus of Estonian Spontaneous Speech. I am very grateful to Pire Teras for managing this project, to all the labelers, and also to all the speakers who have volunteered to be recorded for the corpus.

Finally, my family – my mother, my wife Liina, and Helmi, Miili, Kusti – thanks for being always there for me.

CONTENTS

LIST OF PUBLICATIONS

[P1] Lippus, Pärtel, Karl Pajusalu & Jüri Allik (2007). The tonal component in perception of the Estonian quantity. In Jürgen Trouvain and William J. Barry (Eds.), *The Proceedings of the 16th International Congress of Phonetic Sciences: 16th International Congress of Phonetic Sciences, Saarbrücken, Germany, 6–10 August 2007* (pp. 1049–1052). Saarbrücken. <http://www.icphs2007.de/conference/Papers/1029/1029.pdf>.

[P2] Lippus, Pärtel, Karl Pajusalu & Jüri Allik (2009). The tonal component of Estonian quantity in native and non-native perception. *Journal of Phonetics, 37*(4), 388–396. <doi:10.1016/j.wocn.2009.07.002>.

[P3] Lippus, Pärtel & Karl Pajusalu (2009). Regional variation in the perception of Estonian quantity. In Martti Vainio, Reijo Aulanko & Olli Aaltonen (Eds.), *Nordic Prosody. Proceedings of the Xth Conference, Helsinki 2008* (pp. 151–157). Frankfurt: Peter Lang.

[P4] Lippus, Pärtel, Karl Pajusalu & Jüri Allik (2011). The role of pitch cue in the perception of the Estonian long quantity. In Sónia Frota, Gorka Elordieta & Pilar Prieto (Eds.), *Prosodic Categories: Production, Perception and Comprehension* (pp. 231–242). Dordrecht: Springer. <doi:10.1007/978-94-007-0137-3_10>.

[P5] Asu, Eva Liina, Pärtel Lippus, Pire Teras & Tuuli Tuisk (2009). The realization of Estonian quantity characteristics in spontaneous speech. In Martti Vainio, Reijo Aulanko & Olli Aaltonen (Eds.), *Nordic Prosody. Proceedings of the Xth Conference, Helsinki 2008* (pp. 49–56). Frankfurt: Peter Lang.

[P6] Lippus, Pärtel (2010). Variation in vowel quality as a feature of Estonian quantity. In Mark Hasegawa-Johnson, Ann Bradlow, Jennifer Cole, Karen Livescu, Janet Pierhumbert & Chilin Shin (Eds.), *Speech Prosody 2010, Chicago, USA*.
<http://aune.lpl.univ-aix.fr/~sprosig/sp2010/ papers/100877.pdf>.

[P7] Lippus, Pärtel & Jaan Ross (2011). Has Estonian quantity system changed in a century? Comparison of historical and contemporary data. In Wai-Sum Lee & Eric Zee (Eds), *Proceedings of the 17th International Congress of Phonetic Sciences* (pp. 1262–1265). Hong Kong: Department of Chinese, Translation and Linguistics, City University of Hong Kong.

[P8] Lippus, Pärtel, Eva Liina Asu, Pire Teras & Tuuli Tuisk (2011). Quantity-related variation of duration, pitch and vowel quality in spontaneous Estonian. Unrevised version of the paper submitted to the *Journal of Phonetics* on April 17th 2011.

1. INTRODUCTION

1.1. Objectives

The three-way quantity has been the most studied feature of the phonetic system of Estonian. The attention is explained by a unique position in the world's languages where more than binary length oppositions are extremely rare, but on the other hand, the nature of the Estonian quantity system has also turned out to be rather complex. In my thesis I focus on two main aspects: firstly, what is the role of the tonal component in Estonian quantity system, and secondly, how are different (possible) acoustic features of Estonian quantity realized in spontaneous speech? Both of these questions are raised from the somewhat contradictory results of previous studies. There have been perception studies asserting that the pitch is a vital cue for distinguishing the long and overlong quantity degree (e.g. Lehiste 1975; Lehiste & Danforth 1977; Eek 1980a, 1980b) while objections have been raised by other studies. Most of the studies have been based on highly controlled lab speech, while the few papers on spontaneous speech show that the quantity-related pitch variation is overshadowed by the intonation and the long vs. overlong quantity opposition can only be based on the temporal cues (e.g. Krull 1993a, 1993b, 1998; Traunmüller & Krull 2003).

In this thesis, perception tests are used to answer the following questions: a) how are the three quantity degrees distinguished if the pitch cue is in contradiction with the temporal structure or missing entirely; b) how is the perception of Estonian quantity attained by L2 listeners; c) whether there are regional differences in the quantity perception within Estonia; d) whether the opposition of long vs. overlong can be obtained by only changing the shape of the pitch curve.

Lehiste (2003) concluded her studies on Estonian quantity by stating that Estonian is undergoing a change from a quantity to an accent language. Historic recordings of Estonian from the time of World War I (for more background see Ross & Nairis 2008) give us a unique chance to compare whether there have been changes in the Estonian prosodic system during the past hundred years.

The analysis of spontaneous Estonian attempts to explain the interaction of the intonation and word-level prosody. In addition, the recent research on the connections between pitch, duration, and spectral cues in the perception of listeners with different language backgrounds (Järvikivi et al. 2010; Lehnert-LeHouillier 2010; Yu 2010) gives a new perspective to the study of Estonian quantity.

1.2. Structure of the dissertation

The present thesis consists of an introductory part and eight publications. The introductory part is divided into seven chapters. Chapter 1 gives an introduction to the thesis, describes the structure of the thesis, and offers a short overview of the publications and author's contributions to the co-authored papers. In Chapter 2 the data and the methods used in this thesis are described. Chapter 3 gives an overview of the previous study of Estonian quantity system. Chapter 4 summarizes the results of the eight publications. Chapter 5 wraps up the thesis with the conclusions and aims for the further research. Chapter 6 is an overview of the thesis in Estonian. Chapter 7 lists the references cited in the whole thesis.

1.3. Overview of publications and author's contributions

The eight publications are divided into two major topics: the first four publications deal with the perception of the pitch cue in Estonian quantity, and the second four publications analyze the acoustic features of Estonian quantity. The co-authors of the papers are aware of the following descriptions and have agreed with them.

[P1] tests the Estonian L1 and L2 listeners' perception of pitch cue in Estonian quantity. Stimuli with re-synthesized segmental duration are used to explore whether the quantity perception of L1 and L2 listeners is affected by a supporting, conflicting, or a missing pitch cue. The first author generated the stimuli, ran the tests and wrote the paper, while consulting the second authors. For writing the introduction of the paper, notes of K. Pajusalu's talk "Bilingualism and Bidialectalism from the Viewpoint of Phonological Typology" (held at the 9th Nordic Conference on Bilingualism, University of Joensuu (Finland), August 10–12, 2006) was used.

[P2] is an extended version of [P1], where Estonian L1 listeners are compared with three groups of Estonian L2 (Finnish L1, Latvian L1 and Russian L1) listeners. The paper was written by the first author while consulting the second authors.

In **[P3]** the same stimuli as in [P1] and [P2] are tested on a larger group of Estonian L1 listeners with various regional backgrounds. The paper was written by the first author while consulting the second author.

[P4] reports a perception test investigating pitch patterns of long and overlong quantity degrees using stimuli with re-synthesized pitch. The first author generated the stimuli, ran the tests and wrote the paper while consulting the second authors. A preliminary version of the Discussion section of the paper was written by K. Pajusalu.

[P5] analyzes the acoustic realization of the temporal and tonal features of the quantity in interaction with intonation and phrasal position in spontaneous Estonian. The acoustic data was analyzed jointly by all four authors. The statistical analysis was done by P. Lippus. All four authors participated in the writing of the paper, while P. Lippus mostly contributed to the results and graphics.

[P6] investigates the quantity related variation of vowel quality in spontaneous Estonian.

[P7] is a diachronic analysis of the acoustic features of Estonian quantity. The data recorded in 1916–1918 from Estonian prisoners of war in the German prison camps was found by J. Ross from the archives of Humboldt University in Berlin. The historic data was compared to the contemporary Estonian. The data was analyzed and the paper was written by P. Lippus. J. Ross commented on the final version of the paper.

[P8] is an extension of [P5] and [P6], where the quantity related variation of segmental duration, pitch patterns and vowel quality is analyzed in spontaneous Estonian. In addition to the data that was analyzed in [P5] and [P6], new data was included. The acoustic analysis was done by P. Lippus and T. Tuisk, in part also by P. Teras. Statistic analysis was done and the first draft of the paper was written by P. Lippus. The submitted version was written by P. Lippus and E. L. Asu while consulting P. Teras and T. Tuisk.

2. MATERIALS AND METHODS

2.1. Perception tests

The stimuli used in the perception tests were re-synthesized from recorded natural speech using the Manipulation function in Praat (Boersma & Weenink 2011). Force-choice perception experiment was carried out using Praat's ExperimentMFC.

2.1.1. Stimuli and test procedure in the case of manipulated duration

For the test stimuli used in [P1], [P2], and [P3] two quantity triplets were used as base words: one for the vowel quantity where the quantity distinction is carried by V1 followed by a short consonant (*sada* [sɑtɑ] 'hundred', *saada* [sɑːtɑ] 'to send, sg imperative', *saada* [sɑːːtɑ] 'to get'), and the other for the consonant quantity where the quantity distinction is carried by the intervocalic consonant after a short V1 (*kada* [kɑtɑ] 'slingshot', *kata* [kɑttɑ] 'to cover, sg imperative', *katta* [kɑtːtɑ] 'to cover'; see the pitch curves in Figure 1). The words were read by a male speaker in a nonsense carrier phrase "*tule ... saama*" ('come … to get') with the test word in a focal position preceded and followed by a disyllabic word. From each of the six words a set of nine stimuli was created by manipulating the duration of either the first vowel (V1) or the intervocalic consonant (C2); a total of 54 different stimuli were created. The stimuli were synthesized so that for the first stimuli the syllable duration ratio (S1/S2) would be smaller than 0.7 (which is typical for Q1) and for the last larger than 2.0 (typical for Q3). The duration of only one sound in the word was changed, starting from 50 ms in nine steps of 30 ms to 290 ms. The locations of the pitch turning points remained proportionally unchanged.

A three-alternative forced-choice perception experiment was carried out in Praat. The nine stimuli from each base word were arranged as one sub-test and presented to the listeners without the carrier phrase with 10 repetitions in random order (i.e. 6 X 9 X 10 = 540 stimuli in total). Each sub-test was preceded by an exercise where the nine stimuli were presented without repetitions. The subjects heard re-synthesized words and had to decide whether they heard a Q1, a Q2, or a Q3 word. They were instructed to think about the meaning of each word and click a button on the computer screen, labelled [1], [2], and [3] accordingly. The subjects were allowed to have a small break between each sub-test. No repeated listening option was available.

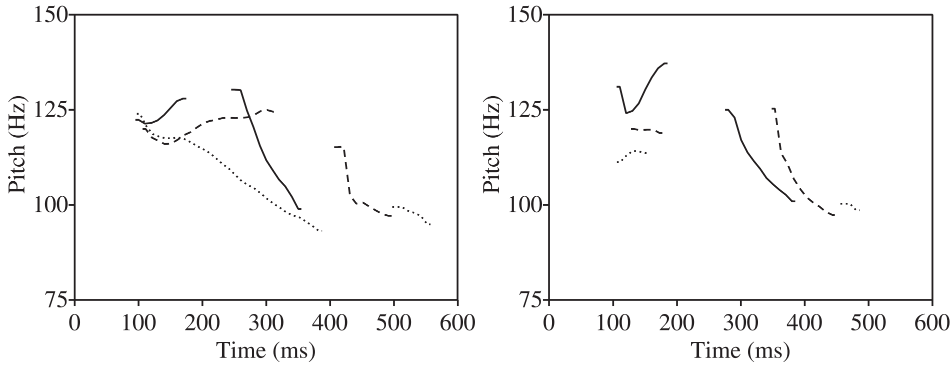

Figure 1. Left panel: the pitch curves in the words [sɑtɑ] (Q1; solid line), [sɑ:tɑ] (Q2; dashed line), [sɑ::tɑ] (Q3; dotted line). **Right panel:** the pitch curves in the words [kɑtɑ] (Q1; solid line), [kɑttɑ] (Q2; dashed line), [kɑt:tɑ] (Q3; dotted line).

2.1.2. Stimuli and test procedure in the case of manipulated pitch

For creating the stimuli used in [P4] a Q2-word saada [sɑ:tɑ] 'send!' was recorded when pronounced in isolation by a male speaker. The syllable duration ratio for the word was 1.4 (according to Lehiste (1997) the typical V1/V2 ratio for Q2 is 1.5 and for Q3 more than 2). Stimuli were re-synthesized by changing the F0 contour of the word while leaving the duration un-manipulated. Four sets of five stimuli were created with a combination of two pattern strategies and two pitch ranges.

For Set 1 and Set 2 five stimuli were created, where the duration of the pitch fall was altered. The locus of the fall was always in the middle of V1. The duration of the fall was varied in five steps from 130 ms in the first stimulus to 0 ms in the last stimulus (see Figure 2). In Set 1, the F0 ranged from 100 Hz to 140 Hz (about 6 semitones), and in Set 2 the F0 varied from 100 Hz to 120 Hz (about 3 semitones; Set 2).

For Set 3 and Set 4 five stimuli were created where the locus of the pitch fall was altered. The pitch fell during 50 ms (about 1/3 of the V1 duration). The start of the fall was varied by five 20 ms increments, resulting in a 10 ms high plateau and 90 ms low plateau in the first stimulus, and 90 ms high plateau and 10 ms low plateau in the last stimulus (see Figure 3). In Set 3 the F0 ranged from 100 Hz to 140 Hz (about 6 st), in Set 4 from 100 Hz to 120 Hz (about 3 st).

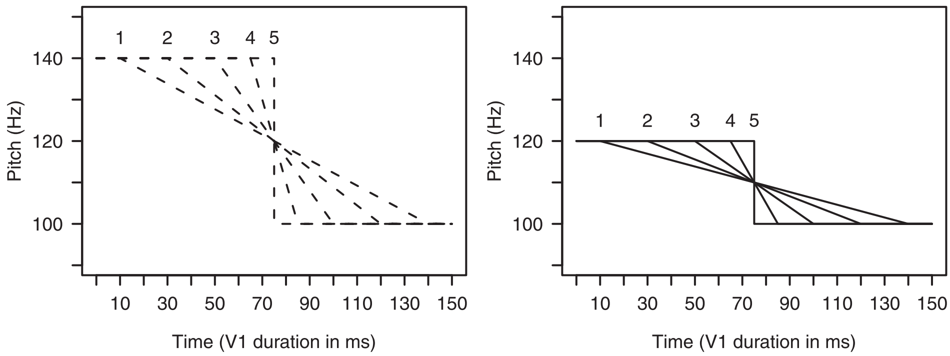

Figure 2. Schematic pitch contours of the V1 of the stimuli. The starting point of the fall is marked with the stimulus number. **Left:** Set 1 with the pitch range from 100 Hz to 140 Hz. **Right:** Set 2 with the pitch range from 100 Hz to 120 Hz. In V2 the pitch continued at 100 Hz in all stimuli.

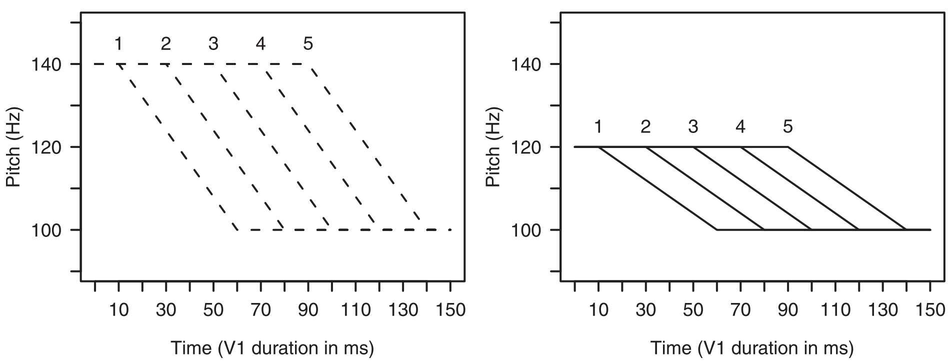

Figure 3. Schematic pitch contours of the V1 of the stimuli. The starting point of the fall is marked with the stimulus number. **Left:** Set 3 with the pitch range from 100 Hz to 140 Hz. **Right:** Set 4 with the pitch range from 100 Hz to 120 Hz. In V2 the pitch continued at 100 Hz in all stimuli.

A forced-choice perception experiment was carried out using Praat. The stimuli were presented to the test subjects in 4 sets of 5 stimuli with 10 repetitions in random order (i.e. 4 X 5 X 10 = 200 stimuli in total). The subjects were told that they will hear synthesized Q2 and Q3 words and were instructed to think about the meaning of the words: ‘send!’ in case of Q2 and ‘to get’ in case of Q3. The subjects listened to the stimuli using headphones and had to decide whether they heard a Q2 word or a Q3 word, and click a button on the computer screen, labelled [2] and [3] accordingly.

2.1.3. Test subjects

In [P1] two groups of test subjects were compared: a group of 9 Estonian L1 listeners and a group of 9 Estonian L2 listeners, who's L1 was Bulgarian, English, Finnish, German, Latvian, Livonian, Norwegian, Russian and Yiddish. In [P2] the test subjects form four groups: 10 Estonian L1 listeners (mostly the same as in [P1]), 6 Finnish L1 listeners, 6 Russian L1 listeners, and 9 Latvian L1 listeners.

In [P3] a larger group of Estonian L1 listeners with various regional backgrounds was tested. The test subjects were 35 undergraduate non-linguistics students at the University of Tartu.

The results of [P4] are from a group of 22 Estonian L1 listeners. The subjects were students and faculty members of the University of Tartu and the Tallinn University of Technology, some of them also participated in the Estonian L1 group reported in [P1] and [P2], but not in [P3].

2.2. Acoustic data

The data in [P5], [P6] and [P8] is from the from the Tartu University Phonetic Corpus of Estonian Spontaneous Speech (http://www.murre.ut.ee/foneetikakorpus/), which currently contains spontaneous dialogues and monologues from 35 speakers (28 h, ~180 000 words in total) and new material is regularly being added. The corpus is manually tagged using Praat (Boersma & Weenink 2011) and contains information about word, segment, and syllable boundaries, the quantity and voice quality.

In [P7] phonograph recordings of the Estonian language made during the First World War from interned soldiers in prisoner-of-war camps of the German Empire are analyzed. The Estonian sound recordings were discovered in the archives of Humboldt University in Berlin by Jaan Ross (for more details see Ross & Nairis 2008). Historical recordings from 8 speakers were selected (one from Saaremaa, three from Võrumaa and four from Tartumaa), where the subjects read a fairy-tale or a story from the Bible. To compare the historic data with contemporary Estonian, contemporary recordings of informants of a similar dialectal background were chosen from the material in the Phonetic Corpus of Estonian Spontaneous Speech. As a side project, the informants whose spontaneous conversations had been recorded for the corpus were also asked to read the story "Põhjatuul ja päike" ('The north wind and the sun') in Standard Estonian. The recordings were made in 2006–2009.

The acoustic data were extracted from the manually annotated TextGrids using Praat scripts. All the measurements were subsequently checked and corrected by hand. In [P5] and [P8] the f0 and the time of a pitch turning point (TP) were determined manually. In [P7] instead of a TP the f0 peak in the disyllabic sequence was found by a script.

2.3. Data analysis

In all papers the data analysis was carried out using the statistical package R (R Development Core Team 2011). In [P2] the perception of the four listeners groups was described using a logistic regression model[1] with the stepwise procedure for selecting the significant factors. In [P6] and [P8] a multinomial logistic regression model[2] described the quantity degree as a function of the measured acoustic features.

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[1] A logistic regression model describes the variation of a binomial dependent variable as a function of the independent variables and predicts a probability of the value being either one or the other.

[2] If the dependent variable has more than two nominal values, a multinomial model is needed. In case the dependent variable has three possible values, the model predicts the probability of the value being A and not B while being also A and not C.

3. PREVIOUS STUDIES OF ESTONIAN QUANTITY SYSTEM

The wider attention to the Estonian quantity system is most likely attributal to Nikolai Trubetzkoy's writings in the 1930s. Based on auditory impressions of one speaker, Polivanov (1928) claimed Estonian having an opposition between four quantity degrees, which besides the temporal features were marked by different tonal patterns. Polivanov regarded the tone in Estonian as a secondary feature in combination with the quantity; it was Trubetzkoy who, from his structuralist point of view in denying the existence of any oppositions in human languages that are more than binary, misinterpreted the notes of Polivanov and introduced Estonian as a tone language (Ross 2005).

The hypothesis of four quantity degrees has been examined by other researchers besides Polivanov (e.g. Remmel 1975). In this case, the opposition of some noun forms in partitive vs. illative case would form the opposition of overlong and super-overlong quantity degrees, e.g.: *lina* 'linen', sg. nom., Q1 – *linna* 'town' sg. gen., Q2 – *linna* 'town' sg. part., Q3 – *linna* 'town' sg. ill., Q4. Inspired by Polivanov, Remmel (1975) did an acoustic survey and found an additional peak in the pitch contour of the words in illative form. Later studies have not verified the existence of Q4, showing that the acoustic variation between Q3 words in partitive and illative is random (Lehiste 1998) and not perceivable (Eek 1980a, 1980b; Lehiste 1998).

Even with only three distinctive quantity degrees, Estonian still is one of the few languages that differentiate between more than two degrees of length. An important difference with other languages where three-way oppositions are reported (Remijsen & Gilley 2008) is that in Estonian quantity is not merely an opposition of three vocalic or consonant durations, but rather a much more complex phenomenon involving both durational and tonal characteristics.

3.1. Temporal structure of Estonian disyllabic feet

One of the first acoustic studies of Estonian quantity was done by Paul Ariste (1939). While talking about a three-way system, Ariste saw quantity as a segmental feature and although he mentioned the half-length of Estonian unstressed syllables, he did not relate it to the length of the stressed syllable. In addition to segmental length, Ariste also pointed out that sound quality and intonation are highly related to the quantity.

The acoustic study of Estonian quantity bloomed in the early 1960s when Ilse Lehiste (1960) in the US and Georg Liiv (1961a) in Tallinn almost simultaneously published their papers on Estonian quantity. Lehiste and Liiv were not the first to study Estonian quantity after Ariste's works in the 1930s (see Hallap 1962 for an overview), but their studies were the most extensive and were the first to present their results on Estonian quantities as a ratio of the stressed and unstressed syllable with pitch as an associated feature.

The domain of Estonian quantity is a disyllabic foot and one of the main features characterizing the quantity opposition is the duration ratio of the syllables in the foot. The quantity is phonologically carried by the stressed vowel, syllable-medial consonants, or a combination of a stressed vowel and the following consonant (see Table 1; for a more detailed overview, see Asu & Teras 2009; Viitso 2003). Unstressed syllables do not exhibit length opposition (Viitso 2003). Due to a certain degree of foot isochrony (e.g. Lehiste 2003; Nolan & Asu 2009), the duration of the second syllable compensates for the durational variation in the first syllable, which means that the unstressed second syllable is the longest in Q1 words and the shortest in Q3 words. Although durational variation in unstressed syllables is not phonological, it is nevertheless important for the perception of the quantity – for instance, it has been shown that the opposition of Q2 and Q3 is not perceived if only the first syllable of a disyllabic sequence is presented to the listeners (Eek & Meister 2003). In monosyllabic words, the quantity is limited to a binary opposition of a short vowel followed by a long consonant (or a consonant cluster) vs. a long vowel (or a diphthong) followed by a short consonant, while words consisting of a single open syllable do not participate in the quantity opposition.

Table 1. Possible combinations of sounds in disyllabic words in three quantity degrees

		Q1	Q2	Q3
Vocalic	Single sound	[sɑ.tɑˑ] 'hundred'	[sɑː.tɑ] 'send!' sg2 imp	[sɑːː.tɑ̆] 'to get' inf
	Diphthong	*	[vɤi.tɑ] 'win!' sg2 imp	[vɤiː.tɑ̆] 'to oil' inf
Consonant	Single sound	[kɑ.tɑˑ] 'slingshot'	[kɑt.tɑ] 'cover!' sg2 imp	[kɑtː.tɑ̆] 'to cover' inf
	Consonant cluster	*	[kɑs.tɑ] 'water!' sg2 imp	[kɑsː.tɑ̆] 'to water' inf
Both	Single sounds	*	[sɑːt.te] 'get' pl2	[sɑːtː.tĕ] 'broadcast' sg gen
	Diphthong and cc	*	[mɑit.se] 'taste' sg nom	[mɑitː.sĕ] 'taste' sg gen

Starting from Lehiste's and Liiv's work in the 1960s, Estonian quantity has mainly been described by comparing the duration of the first and second syllable of a foot. Since the duration of the syllable-initial consonant is not contrastive, the syllable onset is usually excluded from comparison, and only the duration ratio of the syllable rhymes is computed. The non-initial syllable begins with a single consonant; in words with a geminate consonant on the syllable boundary, the geminate is divided so that the second part belonging to the second syllable onset has approximately the same duration as the corresponding singleton consonant. The typical S1/S2 ratio is 0.7 in a Q1 foot, 1.5 in a Q2 foot, and 2.0 in a Q3 foot (Lehiste 1960, 1997). Similar results are also reported by others (e.g. Liiv 1961a; Krull 1991, 1992; Eek & Meister 1997).

The syllable duration ratio is a good characteristic for describing the production of Estonian quantity, but it has been criticized from the point of view of perception. Traunmüller & Krull (2003) found a number of reasons why comparing the S1/S2 duration ratio might not work for perception. Traunmüller & Krull argue that if the quantity degree is identified by the S1/S2 ratio, the second syllable should have the same perceptual weight as the first syllable. Furthermore, if the consonant in the position of C2 is a geminate, the syllable boundary should lie somewhere within the geminate, therefore there is no objective way to find it. The importance of pitch as the main cue for distinguishing Q3 from Q2 has also been questioned, as in many cases there is a voiceless consonant in the S1 rhyme. Instead of the S1/S2 ratio in combination with the pitch contour, Traunmüller & Krull (2003) suggest that the quantity is identified by comparing the V1 duration with the weighted sum of segment durations within the foot. The effect of neighboring segment duration has also been tested by Eek & Meister (2003, 2004), who propose a model for production and perception of the quantity degrees where the durations of the S1 nucleus, S1 coda (in case of Q2 and Q3), and S2 nucleus are compared, while the syllable onsets indicate the local speaking rate. For describing production, this model may be slightly more precise, but one still has to find the imaginary syllable boundary if the consonant in C2 position is a geminate, and also postulate the imaginary nucleus/coda boundary in the case of long V1.

3.2. Pitch as the secondary feature of Estonian quantity

The first acoustic study of quantity-related pitch variation of Estonian was done by Elin Põldre (1938). Her results show that in general, the length of the vowel is correlated with the pitch height. In Q1 the pitch rises slowly from the beginning to the end of the first syllable and stays on the same level until the end of the word. In Q2 the pitch movement is similar with a wider range than in Q1, while in Q3 the pitch is fairly high already in the beginning, but rises suddenly even higher, and by the end of the word it falls quite low.

Põldre's descriptions sound a bit lumbering, but match the later descriptions of Estonian quantity-related pitch variation rather well. According to the traditional view, one that has been carried on since the 1960s, the pitch contour is rising-falling in all quantity degrees, but in Q1 and Q2 words the position of the peak is at the end of the first syllable, while in Q3 words it is in the beginning of the first syllable (Lehiste 1960; Liiv 1961a; Remmel 1975). By looking only at the first syllable, the pitch contour has been described as ‘level’ or ‘rising’ in Q1 and Q2 but ‘falling’ in Q3 words (Liiv 1961a). For Q1 and Q2 the term “rising-returning” has also been used, meaning that the pitch rises in the beginning but returns to the initial level at the end of the syllable. In the second syllable the pitch falls abruptly in Q1 and Q2, but more gently in Q3 (Lehiste 1960).

The main difference in the overall pitch contour between the quantity degrees is the distribution of the high pitch and the fall, or the location of the peak. In Q1 and Q2 words the peak is located at 3/4 of the first syllable duration, but in Q3 words the peak is at 1/4 of the first syllable duration (Liiv 1961a; Remmel 1975). In Q1 and Q2 words there is a high pitch before a fall at the end of the first syllable, but in Q3 words the high pitch turns to a fall in the first half of the first syllable. Within the whole foot, the tonal peak is at the end of the nucleus of the stressed syllable in Q1 and Q2, but falls noticeably in the unstressed syllable. In Q3, the pitch starts falling in the first half of the stressed syllable and the fall continues in the unstressed syllable.

3.3. Perception of the pitch cue

Perception studies have shown that the pitch cue is crucial for distinguishing Q2 and Q3. Lehiste (1975) used synthesized stimuli with various S1/S2 duration ratios and three different pitch contours: level pattern (monotone 120 Hz), step-down pattern (S1 120 Hz, S2 80 Hz; typical for Q2), and falling pattern (S1 120–80 Hz, S2 monotone 80 Hz; typical for Q3). The results showed that with flat F0 the judgment of the stimuli as Q2 or Q3 depended mostly on the temporal structure. If the pitch contour was falling, Q3 was favored, but if the pitch was the step-down contour, Q3 was not recognized even if the temporal structure was typical for a Q3 word. Q1 was discriminated from Q2 in all the pitch patterns.

A similar experiment was conducted by Eek (1980a, 1980b) using re-synthesized natural speech stimuli wherein the duration of V1 and/or V2 was manipulated. The F0 of the base words was rising in Q1 and Q2 words and falling in Q3, and it remained unmodified in the stimuli presented to subjects. The results showed that if only the temporal structure was modified, Q1 and Q2 could be converted into each other. It was not possible to obtain an acceptable Q3 from a Q1 or a Q2 word by modifying the duration, nor could a natural Q1 or a Q2 word be obtained from a Q3 word (Eek 1980a). Q3 was perceived from Q1 and Q2 words only if the pitch was modified from rising to falling and the S1/S2 duration ratio was typical for Q3 (Eek 1980b).

Based on the results from Lehiste (1975), Lehiste and Danforth (1977) present a hierarchy of phonetic cues for the perception of Estonian quantities where pitch cue follows after the duration of V1 (or S1 rhyme in case of consonant quantity). Based on all of her perception tests, Lehiste concludes that the quantity opposition is binary; syllable ratios discriminate short from long, but for the discrimination of long and overlong, the pitch is vital (Lehiste 1997, 2003). Eek concludes that Estonian quantity is durational-accentual: Q1 vs. Q2 is an opposition of short and long, but Q2 vs. Q3 is an opposition of lax-long and tense-long (Eek 1980b).

3.4. Vowel quality as an additional feature of quantity

Ariste (1939) noted that the sound quality is strongly affected by the quantity; the quality of short and long vowels do not differ much, but the variation between the quality and intensity of long and overlong vowels is significant in most of the Estonian dialects. Probably the most exhaustive study of Estonian vowel system has been done by Georg Liiv using x-ray filming and classical palatography (Liiv 1961b), and spectrographs (Liiv 1962). He found that the articulation place of the vowels is different in all quantity degrees and the overlong vowels are produced with greater muscular tension of the speech organs (Liiv 1961b). This was confirmed by acoustic data: short vowels are the most centralized and the overlong vowels are the most peripheral, with the greatest difference mainly between long and overlong vowels. (Liiv 1962). If Liiv's results were converted from Hertz to Bark scale, the differences between Q2 and Q3 vowels would exceed 1 Bark, which is often considered as the just noticeable difference (JND) level of the vowel quality.

Later studies have confirmed the relation between vowel quality and quantity, but the effect is relatively small. As the stressed vowels in Q3 feet and the unstressed vowels in Q1 feet are the longest in duration, they also are more peripheral, while the shortest and the most centralized are the stressed vowels in Q1 feet and unstressed vowels in Q3 feet. Eek & Meister (1998) claim that this variation does not exceed one Bark and therefore is not perceivable. Even if this variation is not enough for considering short and long vowels as different vowel categories, the variation should be significant for evaluating the subjective duration and therefore should be considered in the description of the quantity system. A study of micro-durational variations in vowel category perception (Meister & Werner 2009) implies that such a link between spectral and temporal cues should also exist in Estonian.

In addition to vowel quality, Ariste also noticed variation in the consonant quality, for example the articulation place of Estonian /t/ moves from prepalatal in Q1 to interdental in Q3 (Ariste 1939). Unfortunately the variation of quality of the consonants as a feature of foot quantity has not yet been systematically studied in Estonian.

3.5. General views on the relations of duration, pitch, and vowel quality

Lehiste (1976) demonstrated that in the case of the same duration, English listeners perceived units with dynamic F0 longer than those with a monotone F0, and when the F0 is rising-falling, units with an earlier peak were perceived as longer. She suggests that this is a universal phenomenon. Indeed, this perceptual phenomenon was later confirmed by others (see Yu 2010 for an overview). Specifically, dynamic F0 on the whole lengthens the subjective duration of the syllable. According to Yu (2010) there is, however, no difference whether the F0 is rising or falling. Vainio et al. (2010) show that also in Finnish, which is regarded as a typical quantity language and F0 does not play a role on the lexical level (Suomi et al. 2008), a longer quantity entails an earlier F0 fall (i.e. the dynamic first syllable in the case of long quantity vs. monotonous first syllable in the case of short quantity). Järvikivi et al. (2010) show that in Finnish, the influence of dynamic F0 operates similarly when judging subjective durations. Their results suggest that the perception of tone and quantity are closely related, and that tone languages and quantity languages share a common perceptual basis. Similar universal relationships as with the dynamic F0 have been found between vowel quality and subjective duration: more peripheral vowels are perceived longer than centralized vowels (Lehnert-LeHouillier 2010).

3.6. Account of spontaneous speech

Most of the studies investigating the realization of Estonian quantity degrees have focused on lab speech and very little research has targeted the issue of the interaction between the tonal characteristics of the quantities and intonation. The results of Krull's (1993a, 1993b, 1997) investigation of conversational speech showed that duration ratios were distinctive between quantities, but the tonal correlates seemed to have no significant tendency. Krull does not, however, take into account utterance level intonation or the position of the quantity words in utterances. Krull's study (1998) on quantity perception on the other hand shows that without their phonological context the majority of Q3 stimuli extracted from spontaneous speech were not recognized.

4. RESULTS AND DISCUSSION

4.1. Estonian quantity perception

In this section the results of the publications [P1], [P2], [P3], and [P4] are discussed. The aim of the perception tests was to specify in what way and to what extent the temporal cues of Estonian quantity are supplemented by the additional pitch cue. In addition, Estonian L2 listeners were tested to see how they have obtained this complex system.

4.1.1. The role of pitch in Estonian quantity perception

In [P1] and [P2] the results of the perception tests with manipulated segmental duration are reported (the stimuli and test set-up are described in Chapter 2.1.1). The results of ten Estonian L1 listeners (see Figure 4) show that the main cue for the three-way quantity distinction is the temporal structure of the word, but a falling pitch in the first syllable is an important cue for perceiving Q3. No matter what the pitch contour was, Q1 was perceived when the S1/S2 ratio was less than 1, and Q2 was perceived when S1/S2 was between 1 and 2, but when the S1/S2 ratio was greater than 2, Q3 was perceived only if the pitch was falling in the first syllable, as is typical for Q3. If the pitch was flat in the first syllable as is typical for Q1 and Q2 words, it was identified as Q3 vs. Q2 at chance levels. However, when the pitch cue was missing in the case of consonant lengthening, all quantity degrees were perceived according to the temporal structure of the stimuli. The main cue for quantity perception is the temporal structure, but Q3 cannot be successfully perceived if the secondary cue is misleading.

The main cue for quantity distinction is the temporal structure of the word. The pitch is not important between Q1 and Q2 and this distinction was always made based on the temporal structure. In cases where the pitch cue is missing (as in words with intervocalic voiceless geminates, e.g. [kɑttɑ] and [kɑtːtɑ]), the distinction between Q2 and Q3 is also done perfectly based only on the temporal cues. The pitch is important only for perceiving Q3. Specifically, Q3 was perceived only when the F0 was falling already in the first syllable and if the pitch was flat in the S1, the distinction between Q2 and Q3 was not made. In general, these results agree with those of Lehiste (1975) and Eek (1980a, 1980b).

As the papers [P1] and [P2] show that a contradiction between the pitch cue and the temporal cues can impede the Q3 perception, the paper [P4] investigates whether Q3 perception can be triggered with a pitch cue and what is the shape of a typical Q3 pitch contour using stimuli with re-synthesized pitch on a Q2 word (the stimuli and the test procedure is described in Chapter 2.1.2).

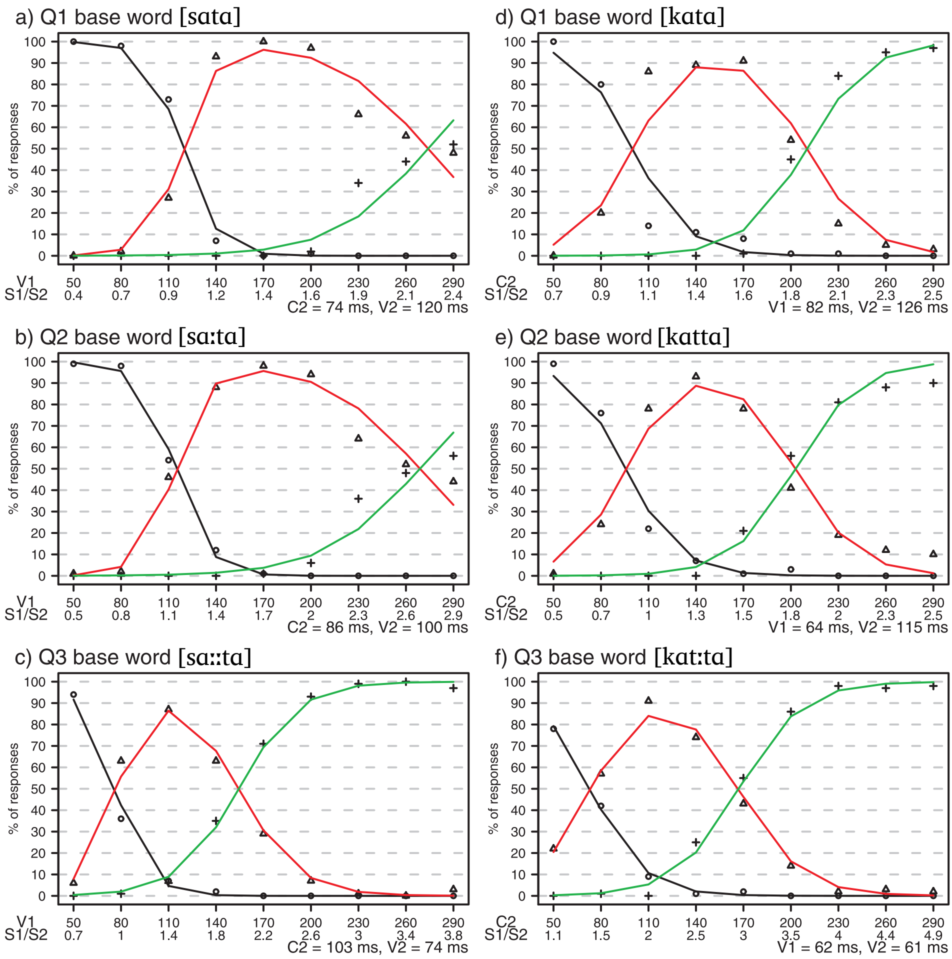

Figure 4. The judgments of ten Estonian L1 to stimuli with manipulated V1 duration (left column) and with manipulated C2 duration (right column). The sub-tests with the Q1 base word are in the first row, the sub-tests with the Q2 base word in the second row, and the sub-tests with the Q3 base word in the third row. The circles represent the actual Q1 responses, the triangles the Q2 responses, and the crosses the Q3 responses. The regression lines represent the approximation of the logistic regression analysis of Q1 and Q3 responses: p_{Q1} with the black line, $1–(p_{Q1}+p_{Q3})$ with the red line, and p_{Q3} with the green line.

The main result of [P4] is that it is possible to generate an overlong (Q3) word by changing the pitch contour of a long (Q2) word. A disyllabic Q2 word with typical duration ratios is perceived as a Q3 word if its ‘level’ pitch contour in the initial stressed syllable is changed to ‘falling’. The optimal Q3 pitch contour comprises a sharp pitch fall and sufficiently long high and low plateaus (see Figure 5). However, the perception of Q3 is disturbed if the duration of the fall is too short. The rate of the Q3 responses was the highest when the fall constituted 13–33% and the high and the low plateau both 33–43% of V1 duration. The placement of the turning point of the pitch contour is important for the perception of Q3. Q2 is usually perceived if the turning point of the pitch is in the very beginning of V1 or in the second half of V1, but if the turning point is at the distance of 20–40% from the beginning of V1, Q3 is most frequently perceived. These results indicate that while both the high plateau and the low plateau have to be sufficiently long in order to perceive Q3, the turning point must be located in the first half of V1.

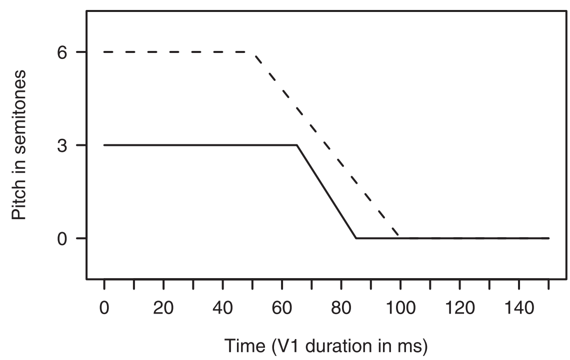

Figure 5. The pitch contours of V1 of the stimuli with the most Q3 judgments.

A similar perception test was repeated by Salveste (2011), who combined the same pitch alteration strategy as described in Chapter 2.1.2 with manipulated temporal structure: three sets of stimuli were re-synthesized where the S1/S2 ratio was: a) typical for Q2, b) typical for Q3, and c) in-between Q2 and Q3. The stimuli were presented to listeners with a context allowing both Q2 and Q3 interpretation. Salveste's results show that if the temporal structure of the stimuli was typical for either Q2 or Q3, they were perceived according to the temporal structure, but if the temporal structure was miscellaneous, the pitch pattern had a decisive effect, similar as described in [P4].

4.1.2. Regional variation in quantity perception

In [P3] the results of a larger group of Estonian L1 listeners to stimuli with manipulated segmental duration (described in Chapter 2.1.1) are reported. The subjects fell into two major groups. Group 1 (18 subjects) was considerably influenced by the pitch cue while Group 2 (17 subjects) was not. The differences between the two groups tended to be based on the dialectal background of the subjects. Figure 6 shows the regional background of the test subjects on the map of Estonia. Among the subjects from western and central Estonian dialect areas, the majority (78%, 14/18) were strongly influenced by the pitch cue (belonging to Group 1), but the tonal effect was not significant for the majority of the subjects from eastern and southern Estonia (24%, 4/17 belongs to Group 1, the others to Group 2). The boundary between the two groups runs along the main borders of the Estonian dialect areas.

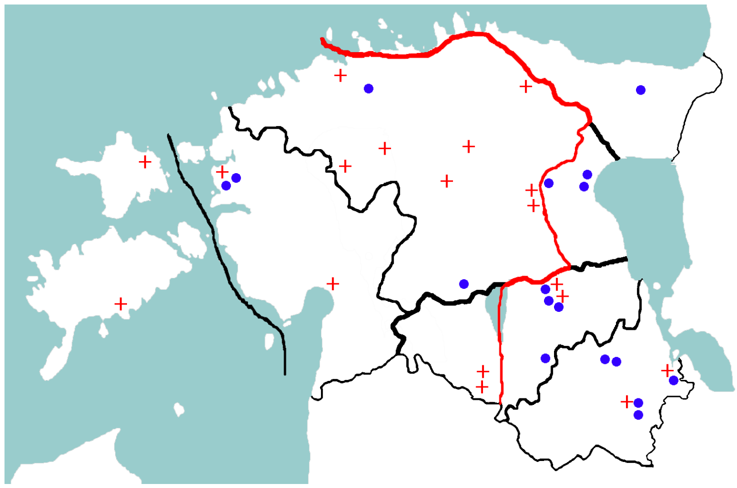

Figure 6. Regional background of the subjects on the map of Estonia showing the main dialect area borders. Group 1 is marked with red crosses, Group 2 with blue dots. The red line runs on the dialect area borders that could mark the boundary between the two groups.

4.1.3. Adaption of Estonian quantity system by L2 listeners

In [P1] a group of 9 Estonian L2 listeners, each with a different L1 was tested with the stimuli described in Chapter 2.1.1. Their results showed that they had successfully obtained the Estonian three-way quantity opposition, but differently from the Estonian L1 listeners group, they were not affected by the pitch cue, and their decisions were not as accurate, as the turn-over points between their judgments were not as sharp as in the Estonian L1 group.

These results were extended in [P2], where three groups of Estonian L2 (Latvian, Finnish, and Russian L1) listeners were tested. On the one hand, these languages are spoken in areas neighboring Estonia and they have all had historical contacts with Estonian; on the other hand, each of these languages have different prosodic systems that make use of acoustic features in a different manner.

The results (Figure 7) show that all the Estonian L2 listeners have learned to distinguish the three quantity degrees of Estonian, but with some differences.

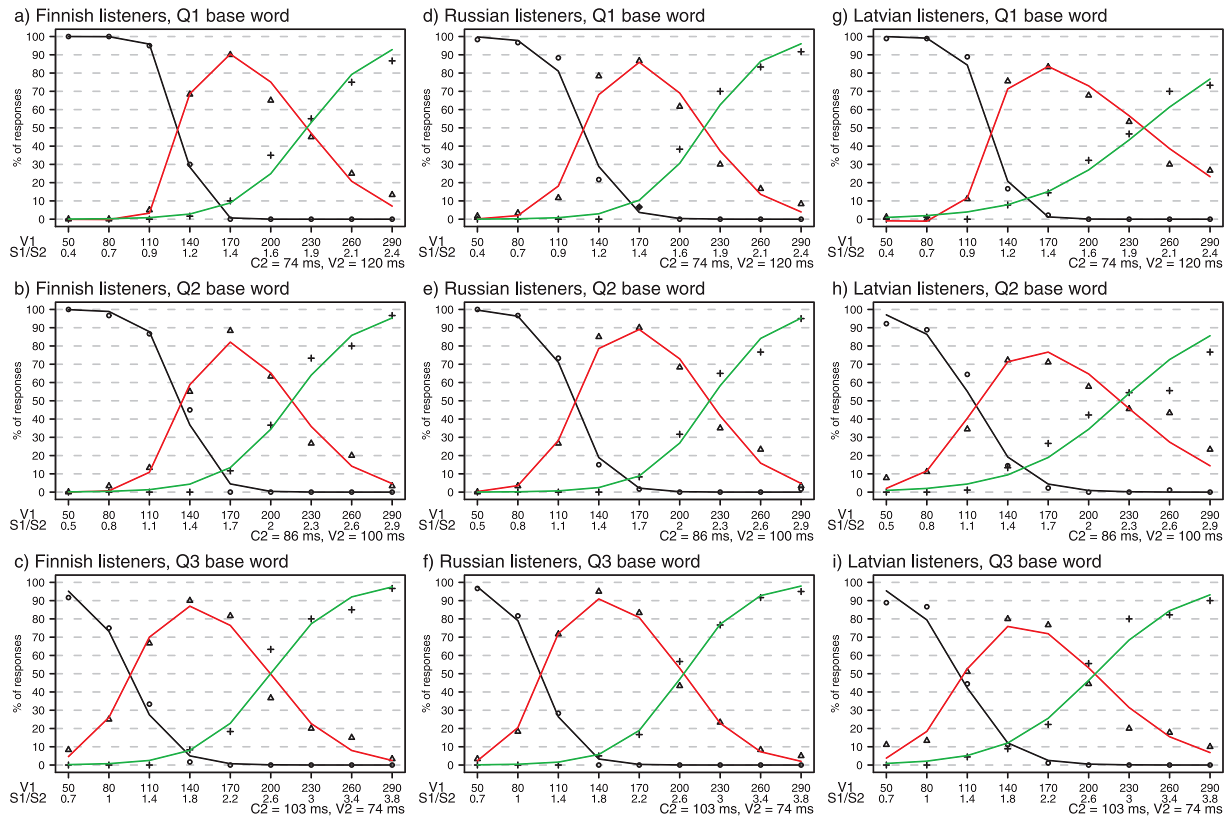

Figure 7. Judgments of Finnish L1 (left column), Russian L1 (mid column), and Latvian L1 listeners (right column) to stimuli with manipulated V1 durations. The sub-tests with the Q1 base word are in the first row, the sub-tests with the Q2 base word in the second row, and the sub-tests with the Q3 base word in the third row. The circles represent the actual Q1 responses, the triangles the Q2 responses, and the crosses the Q3 responses. The regression lines represent the approximation of the logistic regression analysis of Q1 and Q3 responses: p_{Q1} with the black line, $1-(p_{Q1}+p_{Q3})$ with the red line, and p_{Q3} with the green line.

For the Finnish L1 listeners the pitch cue had no effect: the three quantity degrees were perceived according to the temporal structure no matter whether the pitch is falling, flat or missing. The results of the Russian L1 listeners were extremely similar to the results of Finnish L1 listeners. It is somewhat surprising that both groups were also successful in distinguishing Q2 and Q3, since Finnish only has a binary durational opposition and in Russian vowel length is a consequence of lexical stress.

In the Latvian L1 group, there was considerably wide dispersion of the Q2 and Q3 responses. Despite the dispersion we can see patterns in the results of the Latvian L1 listeners that are more similar to the Estonian L1 group. While in Estonian pitch and duration are both used to signal the three-way quantity opposition, in Latvian pitch is used to signal different lexical tones, and duration is used for the opposition of short and long segmental quantity. This system, when applied to perception of Estonian, would hypothetically use the temporal structure for distinguishing between Q1 and Q2, but only pitch for distinguishing Q2 and Q3, e.g. the Estonian three-way quantity opposition is divided between two separate categories. If this is the case, Latvian L1 listeners would be expected to rely even more heavily on the pitch cue in Estonian. They may have learned to identify the quantity degrees by durational cues, but the conflicting pitch cue interferes with the actual decision. This would also explain the poor recognition of Q2 and Q3 in the sub-tests, where the pitch cue was missing due to the voiceless stop.

4.2. Acoustics of Estonian quantity

In this section the results of the publications [P5], [P6], [P7], and [P8] on acoustic characteristics of Estonian quantity are discussed. In [P5], [P6], and [P8], the data from the Phonetic Corpus of Estonian Spontaneous Speech is analyzed. In [P5], the main issue is whether the quantity-related variation of segment duration and pitch follow the same patterns in spontaneous speech as it has been described in lab speech or is it overshadowed by the phrase-level intonation. [P6] focuses on the possible quantity-related variation in vowel quality that could be viewed as an additional feature similar to the variation of the pitch patterns. Finally, [P8] searches for a trade-off between the three acoustic features of the quantity. The same issue, the trade-off between duration and pitch, is viewed in [P7] from a diachronic aspect, analyzing historic phonograph recordings from the past century.

4.2.1. Interaction between the word prosody and the phrase-level intonation

The previous study on spontaneous Estonian (see Chapter 3.6) has shown the acoustic features of the quantity are not stable in connected speech as they are overshadowed by the phrase-level intonation. [P5] suggests that the patterns described in lab speech can also be found in spontaneous speech, if the phrase-level variation is kept in mind. In [P5] words with two open syllables were extracted from recordings of spontaneous dialogues of 7 Estonian speakers. The words were labeled by the position in the phrase, stress conditions, and intonational pitch accent. A total of 348 words was found that carried either an H*+L pitch accent or were unstressed and thus deaccented.

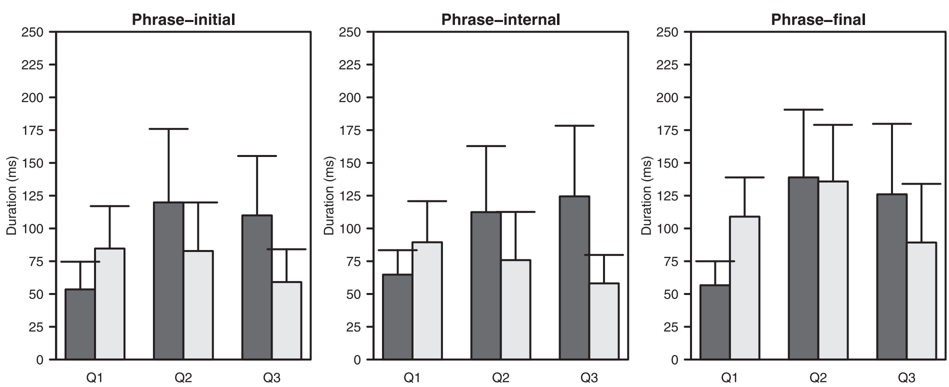

Figure 8. Mean durations and standard deviations of V1 and V2 in accented words. Dark gray bars represent V1 and light gray bars V2.

The analysis showed that the effect of the phrasal position was significant. The difference between phrase-initial and phrase-internal words was small but the phrase-final words were greatly affected by boundary lengthening (see Figure 8) that prolonged the duration of the unstressed vowel. Also the overall pitch range in the phrase-final words was greater.

In words with H*+L pitch accent, the duration of V1 and V2 was contrastive only between Q1 and Q2, but not between Q2 and Q3. The syllable duration ratio on the other hand was contrastive between all the three quantity degrees. The pitch curves of the phrase-internal words are presented in Figure 9. The pitch pattern was significantly different between Q2 and Q3 in a generally similar manner as has been traditionally described. However, the term “rising-falling” does not describe the pitch pattern, but rather that the pitch has a high plateau in the first syllable after which it turns into a considerable fall. The location of the point where the pitch starts to fall (turning point, TP) matches the traditional description of the peak, being near the end of the first syllable in the case of Q1 and Q2, but in the first half of the first syllable in the case of Q3.

The phrasal position has an effect on the total pitch range of the word, being the greatest in the end of the phrase, but the total pitch range is not significantly different between the quantity degrees.

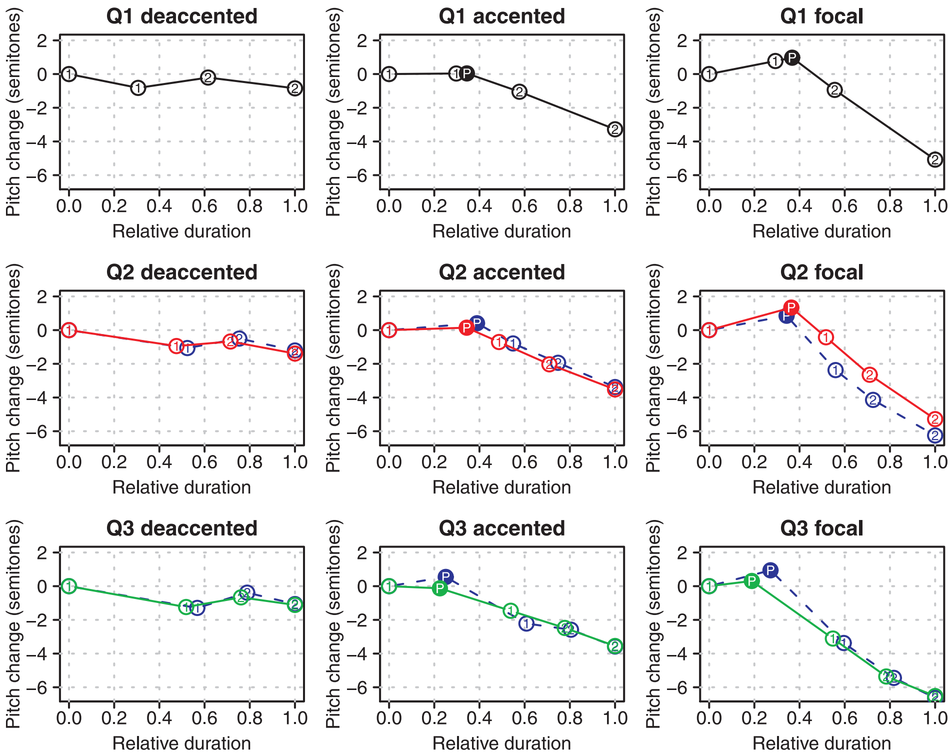

Figure 9. Pitch contour in phrase-internal words with different accent conditions. The Y-axis shows the pitch movement normalized relative to the beginning of the word, the x-axis shows the relative duration of the word. Solid lines represent words with vocalic quantity (open S1; colors black, red and green correspond to Q1, Q2 and Q3, respectively), dashed lines words with consonant quantity (closed S1; blue for both Q2 and Q3). Circles with "1" and "2" mark the measured pitch points at the beginning and end of S1 and S2 respectively, the TP is marked with "P".

4.2.2. Vowel quality as a secondary feature of the quantity

This question is first addressed in [P6] and extended in [P8]. In [P6] only words with the so-called vocalic quantity (i.e. with an open stressed syllable in all quantity degrees) were analyzed, but in [P8] words with the consonant quantity (i.e. with a short vowel in a closed stressed syllable in Q2 and Q3) were also included.

In Figure 10, the vowels are plotted in the space of F1 and F2 (the vowels /y, ø, ɤ/ and the unstressed vowel /o/ were left out of the picture because there were fewer than five observations of each vowel in Q2 and Q3 words). Stressed vowels are closer to the center in Q1 and more peripheral in Q2 and Q3, but there is not much difference in V1 quality between Q2 and Q3. Especially for female speakers, high vowels are more centralized in front-back direction and low vowels are more centralized in high-low direction. [P6] concluded that the vowel quality is an additional feature for distinguishing Q1 from Q2. Considering also the quality of the short vowels in Q2 and Q3 words with consonant quantity, it is clear that the link between quantity and quality is not explicitly a feature of the three-way foot level quantity, but a feature of segmental duration. The quality of the short stressed vowels in the consonant quantity Q2 and Q3 words is similar to that of the short vowels in Q1. Hence, the quality difference between the short and long vowels should be perceivable (exceeding the 1 Bark JND level) and thus presumably is a secondary feature of vowel length.

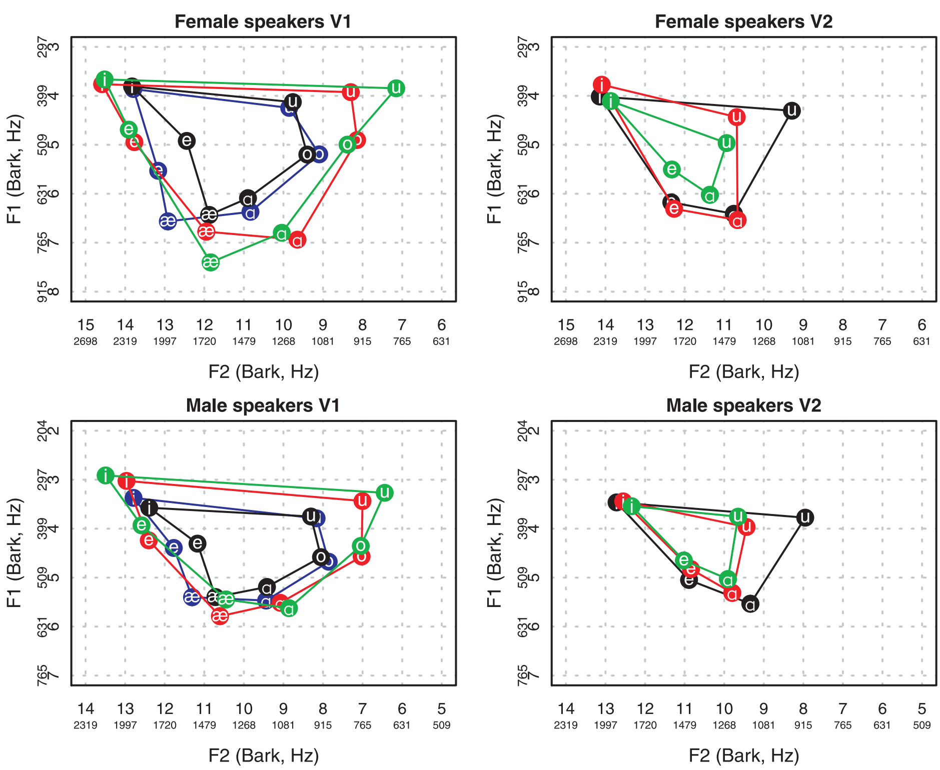

Figure 10. Stressed and unstressed vowels in the space of F1 and F2: vowels from Q1 words (black), vowels from vocalic Q2 words (red), vowels from vocalic Q3 (green), short vowels from consonant quantity Q2 and Q3 words (blue).

Unstressed vowels show more variation in general, but this variation is not entirely due to quantity. The location of an unstressed /e/ in formant space is that of the low front vowel /æ/ in the feet of all quantity degrees. In Q3 feet, the front vowels show less variation due to the quantity degree, but the back vowels, especially /u/, centralize more in Q2 and Q3.

4.2.3. Has Estonian word prosody changed during the past century?

The origin of the Estonian three-way quantity system has been explained by the Great Rhythm Shift theory that was activated by a number of sound changes that took place since the 13th century (Kask 1972; Eek & Help 1987). Lehiste (2003) claims that the Estonian prosodic system is still undergoing a change from a quantity language to a pitch-accent language. The historic phonograph recordings of Estonian from 1916–1918 that are analyzed in [P7] give a unique opportunity to discover possible changes that have taken place during the past century.

Albeit the speech rate in the early recordings is much slower than it is in the contemporary recordings, the temporal structure of the disyllabic words is extremely similar. The S1/S2 ratio (see Figure 11) is contrastive between the quantity degrees in both the early and contemporary recordings, and the figures for Q1 and for Q2 are highly comparable between the two groups. The difference between Q2 and Q3 words on the other hand is more contrastive in the early recordings than they are in the contemporary data.

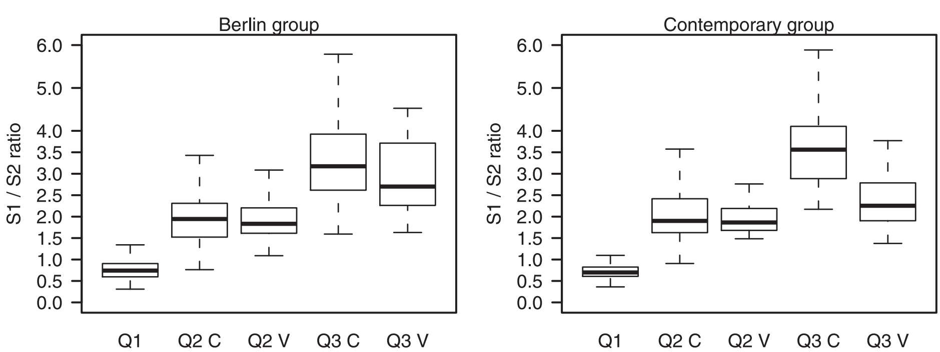

Figure 11. S1/S2 ratio in the historic (left) and the contemporary (right) group. The letter C is added to the quantity reference of groups of words with a closed S1, while V is used to denote an open S1.

The pitch analysis (see Figure 12) showed that the pitch contours in the early data follow the same pattern as it has been described previously: the peak in Q3 words is considerably earlier than in Q1 and Q2 words. However, on the absolute time scale, the F0 peak is always at about 100 ms from the beginning of the stressed vowel and the difference in the relative location of the peak within the stressed syllable is merely due to the different duration of the syllable. In the contemporary data on the other hand the F0 peak can occur in the very beginning of the syllable or in the middle of the word, and the two locations occur with all quantity degrees. Yet with small variations between the dialect areas, in Q1 and Q2 the peak is usually in the second half of the stressed syllable, but in Q3 it is mostly in the beginning of the word.

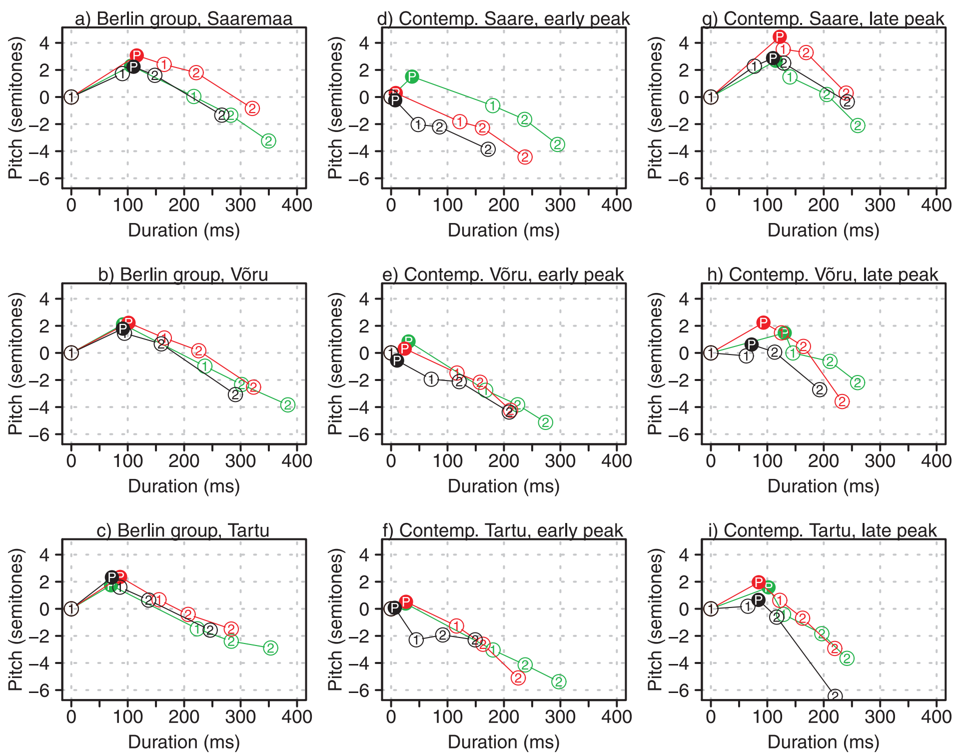

Figure 12. Pitch curves for the historic and contemporary groups. The zero corresponds to the beginning of V1 (black lines Q1, red lines Q2, and green lines Q3; the beginning and the end of S1 is marked with “1”, the beginning and the end of S2 with “2”, and the peak with “P”).

Thus in the past century a slight change has taken place in the direction that Lehiste (2003) pointed. Hundred years ago the foot level three-way quantity was manifested by the temporal structure and the F0 contour was a complementary feature, but now the temporal structure is less contrastive between Q2 and Q3 while the additional pitch pattern has more independence from the temporal structure.

4.2.4. Trade-off between the acoustic features of the quantity

In [P8] the quantity-related variation of segmental duration, pitch pattern, and the vowel quality in spontaneous Estonian is analyzed together using a multinomial logistic regression model. The multinomial regression model is built using 1716 words from the Phonetic Corpus of Estonian Spontaneous Speech including words that were deaccented, words with H*+L accent, and words carrying a focal stress. The model could be improved if it could use the accentuation and focal conditions and other additional data, but in this case a single model for describing the whole data set was needed and taking the additional factors into account would have required separate models for each condition. The quantity of the word is analyzed as a function of segment durations[3], the pitch[4], and vowel quality[5].

The model presented in Table 2 shows that in both opposition of Q1 vs. Q2 and Q2 vs. Q3 the duration of all segments is important. In the case of Q1 vs. Q2, V1 and V2 quality but not the F0 pattern is also significant, while it is just the opposite in the case of Q2 vs. Q3. On the other hand, the variation in the vowel quality is significantly related to vowel duration and it is not exactly a feature of the foot level quantity. The temporal structure is the most important characteristic of the Estonian quantity system. The pitch is an important secondary feature for distinguishing between Q2 and Q3, but the vowel quality is a secondary feature of the vowel length and in the case of consonant quantity it is not distinctive. The trade-off between the acoustic features was not detected; all the features are more distinctive in words with focal accent and less distinctive in deaccented words. It seems that pitch and vowel quality are side-effects of the temporal variation.

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[3] This model was built on words with two different structures (the vocalic quantity and the consonant quantity). Instead of using the duration of the stressed vowel and the duration of the following consonant as separate factors, duration of the S1 rhyme was used. Thus the segments which duration was included as a factor were: (1) S1 onset, (2) S1 rhyme, (3) S2 onset, (4) S2 rhyme.

[4] Instead of the turning point, pitch range in the stressed syllable was used. Though TP is the distinctive feature between Q2 and Q3, the data also includes deaccented words where TP is not available. The pitch range in S1 is an implication of TP location: in Q1 and Q2 TP is near the end of S1, the pitch falls less from TP to S1 end and thus the pitch range in S1 is small, while in Q3 words TP is early in the S1, the pitch has more time to fall from TP to S1 end, and thus the pitch range in S1 is great. The pitch range is also small in all quantity degrees in words that are deaccented, but the range is still measurable.

[5] For describing the vowel quality the Euclidian distance of each vowel from the hypothetical midpoint of the speaker's formant space (as described in Harrington 2010) on Bark scale was calculated.

Table 2. Multinomial logistic regression analysis of the quantity of the foot (Q2 as the reference level)

	b	S.E.	t	Pr(>|t|)	exp(b)
Q1 vs. Q2					
Intercept	5.359	0.698	7.676	0.000 ***	
C1 duration	–0.014	0.006	–2.507	0.012 *	0.986
S1rhyme duration	–0.130	0.009	–13.826	0.000 ***	0.878
C2 duration	0.036	0.008	4.434	0.000 ***	1.036
V2 duration	0.080	0.008	10.209	0.000 ***	1.084
S1 f0 range	–0.105	0.133	–0.783	0.433	0.901
V1 Euk. distance	–0.782	0.146	–5.351	0.000 ***	0.457
V2 Euk. distance	0.660	0.149	4.426	0.000 ***	1.935
Q3 vs. Q2					
Intercept	–2.493	0.443	–5.629	0.000 ***	
C1 duration	–0.011	0.004	–2.824	0.005 **	0.989
S1rhyme duration	0.025	0.003	9.807	0.000 ***	1.026
C2 duration	0.027	0.005	5.510	0.000 ***	1.028
V2 duration	–0.040	0.005	–8.420	0.000 ***	0.961
S1 f0 range	0.407	0.066	6.134	0.000 ***	1.502
V1 Euk. distance	0.051	0.089	0.570	0.569	1.052
V2 Euk. distance	–0.065	0.103	–0.630	0.529	0.937

*** stands for $p < 0.001$, ** $p < 0.01$, and * for $p < 0.05$.

5. CONCLUSIONS

In this thesis the Estonian quantity perception and acoustics was studied from different aspects. The central issue was the role of the pitch contour, and the interaction between different acoustic features in the Estonian word prosody. In addition to this objective, the regional variation of the quantity perception, the acquisition of Estonian by Estonian L2 listeners, and the diachronic aspects of the Estonian word prosody are discussed.

The study of spontaneous Estonian shows the importance of the pitch in Estonian word prosody. If the phrase-level intonation is considered, pitch as a decisive factor between Q2 and Q3 can be observed not only in lab speech but also in connected speech. Based on the data from spontaneous speech and perception tests, the pitch patterns of the three quantities can be described as follows. In the case of H*+L intonation in stressed syllables in all quantity degrees there is a high-pitched plateau during which the pitch movement is insignificant. The high plateau ends at the point where the pitch turns sharply to a fall. The location of this turning point varies between the quantity degrees significantly. In Q1 and Q2 words TP is located near the end of the stressed syllable while in Q3 words it is in the middle of the stressed syllable. In Q3, the stressed syllable has to include a perceivable high part and a perceivable falling part. The perception tests show that the pitch is decisive cue for Q3 vs. Q2 identification. The conflict between Q2 level pitch in the stressed syllable and Q3 temporal structure fails the perception of Q3 on the one hand, and on the other hand the falling pitch in stressed syllable can evoke Q3 perception also in case of Q2 temporal structure.

A diachronic analysis allows us to see that Estonian is going through a typological change moving from a quantity language to a pitch accent language. Though the results are based on a rather small data set, it seems that in 1910s the temporal features had a stronger contrastive power than at present. In contemporary Estonian speech, the contrastive power of the pitch pattern has risen. Nevertheless, even if there is a change in the direction that the Q1 vs. Q2 is an opposition of temporal structures, and the Q2 vs. Q3 is an opposition of pitch patterns (or lax and tense accents as Eek 1980b puts it), this change is still in progress and the opposition of Q2 vs. Q3 is still manifested primarily by the temporal structure.

And yet the power of the pitch cue in perception of Q2 vs. Q3 varies regionally in Estonian. Listeners from Central and Western Estonia are more sensitive to the pitch cue than listeners from Eastern and Southern Estonia. The Western parts of Estonia have historically been areas of mixed settlement of Estonian and Swedish speaking inhabitants (i.e. language with tonal accents) while eastern parts of Estonia have had more historic contacts with the Russian language and the northern coastal parts with the Finnish language. The influence of language contacts on the development of Estonian word prosody would be an important question for further research.

The hypothesis of a trade-off between the acoustic features of the quantity was unsupported by the spontaneous data. The contrastiveness of all the features between the quantities was related to the accentuation level; there was more overlap between the temporal features in the case of deaccented words where the pitch was also flat, while the temporal structure was more distinctive in case of focally-stressed words where the pitch patterns were also emphasized.

Recently, more attention has been paid to the influence of the pitch and spectral movements to the perceived duration, which supposedly is a universal phenomenon in the world's languages. The findings on Finnish (and other languages) implicate that the temporal and tonal features are interrelated in both quantity and tone languages. Variation of the Estonian pitch and vowel quality can be also seen as a feature of perceived duration. However, the pitch pattern in Estonian seems to be more independent from the temporal features than it is in Finnish.

The Finnish L1 and the Russian L1 listeners did not reveal an influence of pitch when perceiving Estonian quantity, which is probably due to the test situation where they showed a learned behavior. They were successful in distinguishing between the three quantity degrees based primarily on the stressed syllable duration. The Latvian L1 listeners were less successful in the perception of Estonian quantity, probably because they were confused by the interaction between temporal and tonal patterns in Estonian, as in their L1 these features are used to manifest two different categories: length and tone.

It is clear that variation in vowel quality is not a feature of the three-way foot level quantity distinction, but is rather related to segmental duration. This variation is not as great as to give a reason to treat short and long vowels as different phonemes. But the variation is great enough to be evaluated as a cue for the perceived duration. A systematic study of quantity-related variation in consonant quality should be considered as a future research perspective.

6. KOKKUVÕTE

Eesti välte akustilised tunnused ja taju

Eesti keele kolmevältesüsteem on kõige põhjalikumalt uuritud eesti foneetika nähtus. Kõrgendatud tähelepanu seletab ainulaadne positsioon maailma keeltes, kus haruharva leidub kvantiteedisüsteeme, mis ei oleks pelgalt binaarne lühikese-pika opositsioon. Aga ka eesti vältesüsteem ise on osutunud üpris keerukaks. Oma doktoritöös keskendun eesti vältesüsteemi kahele aspektile: esiteks, mis roll on toonikontuuril, ja teiseks, kuidas realiseeruvad erinevad vältega seotud akustilised tunnused spontaankõnes. Mõlemale küsimusele on varasemad uurimused andnud mõnevõrra vastukäivaid vastuseid.

Foneetiliselt on eesti välde kahesilbilise kõnetakti ehk jala nähtus. Kolme väldet eristavad kahesilbilise kõnetakti erinevad kestusmustrid ja erinev põhitoonikontuur (Lehiste 1960, 1997; Liiv 1961a). Tajukatsetega (nt Lehiste 1975, 1997; Lehiste ja Danforth 1977; Eek 1980a, 1980b) on kindlaks tehtud, et põhitoonikontuur on teise ja kolmanda välte eristamisel määrava tähtsusega, kuid neile tulemustele on esitatud ka olulisi vastuväiteid. Nimelt, kui enamik varasemast uurimistööst põhineb laborikõnel, siis üksikud spontaankõnet uurivad tööd on näidanud, et lausungi intonatsioon allutab vältega seotud põhitooni varieerumise ning et teise ja kolmanda välte vastandus saab baseeruda ainult temporaalsetel tunnustel (nt Krull 1993, 1998; Traunmüller ja Krull 2003).

Käesolev doktoriväitekiri koosneb sissejuhatavast peatükist ja kaheksast publikatsioonist. Sissejuhatavas peatükis antakse ülevaade uurimisvaldkonnast ja võetakse varem avaldatud artiklite tulemused ühtse käsitlusena kokku. Kaheksa töös esitatud publikatsiooni jagunevad kahe peamise teema vahel: eesti vältetaju ja välte akustilised tunnused. Esimesed neli artiklit on keskendunud põhitooni rollile eesti keele vältetajus ja teised neli analüüsivad eesti välte akustilisi tunnuseid. Kõrvalteemadena on töös uuritud vältetaju regionaalset varieerumist, eesti keele kui teise keele (L2) omandamist ja eesti sõnaprosoodia diakroonilist arengut.

Tajukatsete abil on otsitud vastust järgnevatele küsimustele: a) kuidas eristatakse eesti keele välteid siis, kui põhitoon on vastuolus temporaalse struktuuriga või põhitoonitunnus puudub hoopis; b) kuidas omandavad eesti keele vältetaju eesti keelt teise keelena kõnelejad; c) kas eesti vältetajus on piirkondlikku variatiivsust; d) kas pika ja ülipika välte vastandust saab edasi anda ka ainult põhitooni kuju muutes.

Lehiste (2003) on võtnud oma välteuuringud kokku väitega, et eesti keel on muutumas kvantiteedikeelest (tooni)aktsendikeeleks. Berliinist Humboldti ülikooli arhiivist leitud eestikeelne materjal, mis on salvestatud aastatel 1916–1918 Saksa sõjavangi sattunud eestlastelt (vt lähemalt Ross ja Nairis 2008), annab suurepärase võimaluse kontrollida, kas ka viimase sajandi jooksul on eesti keele sõnaprosoodias toimunud mingeid muutusi.

Spontaankõne akustilise analüüsi abil püütakse selgitada lause intonatsiooni ja sõnaprosoodia vahekorda. Lisaks sellele annavad eesti vältetunnuste käsitlemisele uut valgust hiljutised soome, hiina jt väga erinevate prosoodiasüsteemidega keelte uuringud (Järvikivi *et al*. 2010; Lehnert-LeHouillier 2010; Yu 2010), mis näitavad, et seos põhitooni, kestuse ja spektraalsete tunnuste vahel võib olla universaalne.

6.1. Materjal ja meetodid

6.1.1. Tajutestide materjal

Tajutestides kasutatud stiimulid resünteesiti loomuliku kõne salvestustest programmiga Praat (Boersma ja Weenink 2011). Praatiga viidi läbi ka sundvalikutega tajukatsed.

Artiklites [P1], [P2] ja [P3] kasutatud stiimulid sünteesiti kahest minimaalkolmikust, millest üks oli vokaalikeskse malliga (*sada* [sɑtɑ], *saada* [sɑːtɑ], *saada* [sɑ::tɑ]) ja teine konsonandikeskse malliga (*kada* [kɑtɑ], *kata* [kɑttɑ], *katta* [kɑt:tɑ]). Igast salvestatud sõnast sünteesiti rõhulise vokaali või vokaalidevahelise konsonandi kestust manipuleerides üheksa stiimulit. Manipuleeritava hääliku kestust muudeti 50 millisekundist 290 millisekundini sammuga 30 ms. Põhitoon jäi stiimulites muutmata (vt joonis 1 lk 14).

Publikatsioonis [P4] kasutatud stiimulid resünteesiti kahesilbilisest teisevältelisest sõnast *saada* [sɑːtɑ]. Sõna esimese ja teise silbi kestuste suhe (S1/S2) oli 1,4, mis on erinevate välteuurimuste põhjal selgelt teisele vältele omane (nt Lehiste (1997) tüüpiline silbisuhe teisevältelise sõna puhul on 1,5 ja kolmandavältelise puhul üle 2). Stiimulid sünteesiti põhitoonikontuuri manipuleerides, jättes häälikute kestused muutmata. Põhitooni kontuuri muutmiseks oli kaks strateegiat: muudeti kas languse pikkust või languse asukohta esimeses vokaalis. Esimesel juhul muudeti rõhulise vokaali keskel põhitooni languse kestust viie sammuga 130 millisekundist 0 millisekundini (vt joonis 2 lk 15). Teisel juhul langes põhitoon 50 ms jooksul (mis on umbes kolmandik esimese vokaali (V1) kestusest). Languse asukoht liikus stiimulites 20 ms sammuga vokaali algusest vokaali lõppu (vt joonis 3 lk 15). Kummagi strateegiaga sünteesiti kaks stiimulikomplekti, kus ühes oli põhitooni ulatus 100–140 Hz (umbes 6 pooltooni), teises 100–120 Hz (umbes 3 pooltooni).

Sundvalikutega tajukatse viidi läbi Praatis. Stiimulid olid grupeeritud stiimulikomplektide kaupa alatestidesse, kus neid esitati kümme korda juhuslikus järjekorras. Katseisikuid instrueeriti mõtlema kuuldud sõnade tähendusele ja selle põhjal otsustama, mis vältes stiimul on.

Artiklis [P1] võrreldakse kahte katseisikute rühma: 9 eesti keelt emakeelena (L1) kõnelejat ja 9 erineva emakeelega eesti keelt teise keelena (L2) kõnelejat. Artiklis [P2] võrreldi 10 katseisikust koosnevat eesti L1 rühma kolme eesti L2 rühmaga: 6 soome emakeelena kõnelejat, 6 vene emakeelena kõnelejat ja 9 läti emakeelena kõnelejat.

Publikatsioonis [P3] oli katseisikuteks 35 TÜ eripedagoogika üliõpilast, kõigi emakeel eesti keel. Artikli [P4] katseisikuteks olid 22 eesti emakeelega TÜ ja TTÜ üliõpilast ja töötajat.

6.1.2. Akustilise analüüsi materjal

Publikatsioonides [P5], [P6] ja [P8] analüüsitud andmed on pärit Tartu Ülikooli eesti keele spontaanse kõne foneetilisest korpusest (http://www.murre.ut.ee/foneetikakorpus), mis hetkel sisaldab spontaanseid dialooge ja monolooge 35 kõnelejalt (28 tundi, u 180 000 sõna). Kogu korpus on käsitsi märgendatud sõna-, silbi- ja häälikutasandil.

Publikatsioonis [P7] analüüsitud materjal on pärit Humboldti ülikooli arhiivist ja on salvestatud fonograafiga Esimese maailmasõja ajal eesti soost Saksa sõjavangidelt (vt lähemalt Ross ja Nairis 2008). Võrdlusmaterjaliks kasutati tänapäevaseid loetud kõne salvestusi sarnase murdetaustaga keelejuhtidelt.

6.1.3. Statistiline andmeanalüüs

Statistiliseks andmeanalüüsiks kasutati programmi R (R Development Core Team 2011). Artiklis [P2] on kirjeldatud nelja rühma vältetaju logistilise regressioonimudeli[6] abil, kasutades oluliste tunnuste leidmisel automaatset segavalikut. Artiklites [P6] ja [P8] on multinominaalse logistilise regressiooni[7] mudeli abil kirjeldatud väldet erinevate akustiliste tunnuste funktsioonina.

6.2. Tulemused

6.2.1. Põhitooni roll eesti vältetajus

Artiklites [P1] ja [P2] käsitletud eesti keelt esimese keelena kõnelejate tulemused on esitatud joonisel 4 (lk 25). Tulemused näitavad, et eesti keele kolme välte eristamisel on põhitunnuseks sõna temporaalne struktuur, aga kolmanda välte tajumiseks on oluline lisatunnus põhitooni langus esimese silbi jooksul. Esimese ja teise välte tajumist põhitoon ei mõjutanud: esimest väldet tajuti alati, kui esimese ja teise silbi suhe oli väiksem kui 1 ja teist väldet, kui silbisuhe oli 1 ja 2 vahel. Aga kui silbisuhe oli suurem kui 2, tajuti kolmandat

[6] Regressioonimudel kirjeldab uuritava tunnuse muutumist sõltumatute tunnuste muutumise kaudu. Logistilise regressiooni puhul on uuritav tunnus nominaalne ja mudel kirjeldab sõltumatute tunnuste kaudu tõenäosust, et uuritava tunnuse väärtus on a ja mitte b.

[7] Multinominaalse logistilise regressiooni puhul võib uuritaval nominaalsel tunnusel olla rohkem kui kaks väärtust.

väldet selgelt ainult siis, kui põhitoon seda toetas. Kui põhitoon oli esimeses silbis lame, nagu ta on seda esimese ja teise välte sõnades ja silbisuhe oli suurem kui 2, ei suutnud katseisikud eristada, kas tegemist on teise või kolmanda vältega. Samas aga juhul, kui põhitoonitunnus puudus, nagu see oli konsonandikeskse malliga stiimulites, kus lühikesele vokaalile järgnes helitu klusiil, tajuti kõiki välteid vastavalt stiimuli temporaalsele struktuurile. Välte tajumise peamine tunnus on seega sõna temporaalne struktuur, kuid kolmandat välte tajumine on takistatud, kui sekundaarne põhitoonitunnus on eksitav. Üldjoontes kinnitavad need tulemused Lehiste (1975) ja Eegi (1980a, 1980b) sarnase ülesehitusega katsete tulemusi.

Kui artiklite [P1] ja [P2] tulemused näitavad, et vastuolu välte temporaalsete tunnuste ja põhitooni vahel takistab kolmanda välte tajumist, siis artikkel [P4] uurib, kas teise ja kolmanda välte eristamist saab tingida ainult muutus põhitoonikontuuris. Artikli põhitulemus on, et tüüpilisest teise välte sõnast saab põhitooni kontuuri muutes kolmandavältelise sõna. Teisevältelist sõna tajuti kolmandavältelisena, kui selle esimese silbi põhitoonikontuur muuta lamedast langevaks. Optimaalne kolmanda välte põhitoonikontuur peab esimese silbi jooksul sisaldama kõrget platood (mille jooksul põhitoon on lame või muutub ebaoluliselt) ja madalat platood, mida ühendab järsk langus (vt joonis 5 lk 26). Ka languse asukoht on välte eristamise puhul oluline: teist väldet tajutakse siis, kui põhitoon langeb rõhulise vokaali alguses või lõpus, kolmandat väldet tajutakse kõige tihemini siis, kui langus on vokaali keskel. Need tulemused osutavad, et kolmanda välte tajumiseks peab rõhulises vokaalis olema nii kõrge kui madal platoo olemas, aga põhitooni langus peab algama rõhulise vokaali esimeses pooles.

6.2.2. Vältetaju piirkondlik varieerumine

Artiklis [P3] esitatakse suurema katseisikute rühma tulemused katsest, kus kasutati manipuleeritud kestustega stiimuleid. Katse tulemuste põhjal jagunesid katseisikud kahte rühma: pooltel katseisikutest (18 katseisikut) mõjutas vastust põhitoon, pooltel (17 katseisikut) ei mõjutanud. Rühmade erinevus tundub olevat seotud katseisikute murdetaustaga: põhitoon oli teise ja kolmanda välte eristamisel oluline tunnus enamikule Lääne- ja Kesk-Eestist pärit katseisikutele (14 katseisikut 18-st ehk 78%) ja ainult väiksele osale Lõuna- ja Ida-Eestist pärit katseisikutele (4 katseisikut 17-st ehk 24%). Piir kahe rühma vahel näikse jooksvat mööda suuremaid Eesti murderühmade piire (vt joonis 6 lk 27).

6.2.3. Eesti vältesüsteemi omandamine eesti keelt teise keelena kõnelejatel

Artiklis [P1] võrreldi eesti keelt esimese keelena (L1) kõnelejaid eesti keelt teise keelena (L2) kõnelejatega. Tulemused näitasid, et L2 eesti keele kõnelejad olid edukalt omandanud eesti keele vältetaju, kuid erinevalt L1 rühmast ei mõjutanud neid põhitoonikontuur ja väldetevahelised üleminekud ei olnud nii selged kui L1 rühmal. Artiklis [P2] vaadeldi eraldi kolme L2 eesti keele kõnelejate rühma (soome, vene ja läti emakeelega). Tegemist on eesti keelega juba ajalooliselt lähedases kontaktis olevate ühe keeleareaali keeltega, samas on vaatluse all oleva nelja keele prosoodiline süsteem erinev. Tulemused (vt joonis 7 lk 28) näitavad, et kõik kolm L2 rühma on õppinud eesti keele kolme väldet eristama, aga mõningate erinevustega. Soome ja vene emakeelega katseisikutele ei ole põhitoon oluline – kolme väldet eristatakse vastavalt stiimuli temporaalsele struktuurile, sõltumata sellest, milline on põhitoonikontuur. Läti L1 rühmas oli teise ja kolmanda välte vastustel küllaltki suur dispersioon, millest hoolimata võis näha, et sarnaselt eesti L1 rühmaga on nad põhitooni suhtes tundlikud. Tulemused on seletatavad L2 katseisikute L1 mõjuga: soome ja vene keeles ei ole leksikaalsel tasandil põhitoonil märkimisväärset rolli (Suomi *et al.* 2008; Kodzasov ja Krivnova 2001), mistõttu jääb põhitoon neil tähelepanuta; aga läti keeles, kus eraldi kategooriatena on nii binaarne pikkusopositsioon kui ka leksikaalne toon (Bond *et al.* 2006; Karins 1996), on läti emakeelega katseisikud eesti keele põhitooni suhtes küll tundlikud, aga neil on raske omandada eesti süsteemi, kus kestus ja põhitoon on sama kategooria nähtused.

6.2.4. Intonatsiooni mõju sõnaprosoodiale

Artikkel [P5] näitab, et kui fraasitasandi intonatsiooni arvestada, saab ka spontaankõne puhul vältega seotud põhitoonivarieerumist kirjeldada nii, nagu seda on tehtud laborikõne puhul. Enamik analüüsitud 348 sõnast olid intonatsioonimustriga, mida autosegmentaalmeetrilise teooria kohaselt märgitakse H*+L (rõhulise silbiga seotud kõrgele põhitoonile järgneb madal põhitoon), või olid rõhutud ja seega deaktsentueeritud. Analüüs näitas, et oluline oli nii sõna intonatsioon kui ka positsioon fraasis. Intonatsioonimustriga H*+L sõnade esimese ja teise vokaali kestus eristas eraldi vaadates ainult esimest ja teist väldet, aga mitte teist ja kolmandat väldet. Silbisuhe seevastu eristas kõiki kolme väldet. Põhitoon (vt joonis 9 lk 31) oli teise ja kolmanda välte sõnade vahel oluliselt erinev, nii nagu traditsiooniliselt seda on kirjeldatud. Põhitoonikontuur ei olnud aga mitte tõusev-langev, vaid rõhuline silp algas kõrge platooga, mille jooksul põhitoon oluliselt ei muutunud, ja millele järgnes otsustav pööre langusele. Platoo lõpp (ehk punkt, kus vähene põhitooni muutmine pöördub märkimisväärseks languseks) vastab traditsioonilistele kirjeldustele tipu asukohast, mis esimese ja teise välte puhul on esimese ja teise silbi piiril, kuid kolmandas vältes juba esimese silbi alguses. Sõna positsioon fraasis mõjutab sõna üldist põhitooniulatust, olles fraasi lõpus suurem kui keskel või alguses, aga väldetel ei ole põhitooniulatuse poolest vahet.

6.2.5. Vokaalikvaliteet kui vältetunnus

Artiklis [P6] on vaadatud vokaalikvaliteeti vokaalikeskse malliga sõnades, artiklis [P8] on juurde võetud konsonandikesksed sõnad (vt joonis 10 lk 32). Vokaalikeskse malliga sõnades on esmavältelised rõhulised vokaalid tsentraalsemad, teise- ning kolmandavältelised perifeersemad, kuid teise ja kolmanda välte vokaalikvaliteedi erinevus ei ole kuigi suur. Konsonandikeskse malliga sõnades aga on lühike rõhuline vokaal teise- ja kolmandavältelistes sõnades pigem tsentraalne, nagu see on ka esmavältelistes sõnades. Seega on selge, et vokaalikvaliteet ei ole seotud jalatasandi vältega, vaid segmentaalse kestusega. Sellegi poolest peaks kvaliteedierinevus lühikeste ja pikkade vokaalide vahel olema tajutav ja seega peaks kvaliteet olema vokaali pikkuse sekundaarne tunnus. Rõhutute vokaalide kvaliteet varieerub üldiselt rohkem, kuid see varieerumine on vähem seotud välte või kestusega. Järgsilbi /e/ häälduskoht on vältest sõltumata madala eesvokaali /æ/ lähedal.

6.2.6. Kas eesti vältesüsteem on viimase sajandi jooksul muutunud?

Eesti kolmevältesüsteemi kujunemist on seletatud suure rütminihke teooriaga. Rütminihe sai alguse häälikukadudest alates 13. sajandist (Kask 1972; Eek ja Help 1987). Lehiste (2003) väidab, et eesti prosoodiasüsteemi muutused kestavad tänini ja eesti keel on liikumas kvantiteedikeelest (tooni)aktsendikeeleks. Artiklis [P7] võrreldakse Esimese ilmasõja aegseid fonograafisalvestusi tänapäevase eesti keelega, et leida, kas muutusi eesti prosoodiasüsteemis on toimunud ka viimase sajandi jooksul.

Kuigi varastes salvestustes on kõnetempo palju aeglasem, on kahesilbiliste sõnade temporaalne struktuur väga sarnane tänapäevasest materjalist mõõdetuga. Silbisuhe (vt joonis 11 lk 33) eristab väldet kõigis vältusastmetes nii varastes kui ka tänapäevastes salvestustes. Ainuke erinevus on see, et tänapäevases materjalis vokaalikeskses mallis ei eristu teine ja kolmas välde nii selgelt üksteisest. Põhitoonianalüüs (vt joonis 12 lk 34) näitas, et põhitoonikontuur järgib sama mustrit, nagu seda on traditsiooniliselt kirjeldatud: põhitooni tipp on kolmanda välte sõnades oluliselt varem kui esimese ja teise välte sõnades. Aga see on nii ainult siis, kui vaadata tipu asukohta esimese silbi suhtes – absoluutsel ajateljel on tipp kõigis väldetes umbes 100 ms kaugusel rõhulise vokaali algusest. Seevastu tänapäevases materjalis leidus kaks põhitoonimustrit: põhitooni tipp võib asuda kas päris rõhulise vokaali alguses või siis kaugemal, sõna keskel, ja seda kõigis vältusastmetes. Väikeste murdeerinevustega on esma- ja teisevältelistes sõnades tipp enamasti hilisem, aga kolmandavältelistes sõnades on tipp tavaliselt sõna alguses. Seega võib tõesti märgata mõningast liikumist Lehiste (2003) osutatud suunas. Saja aasta eest olid eesti keele kolm väldet manifesteeritud jala temporaalse struktuuri kaudu, mida saatis veel lisaks põhitoonitunnus, kuid tänapäeval on teise ja kolmanda välte eristuse puhul vähem kaalu kestussuhtel, mistõttu põhitoonikontuuri tähtsus on suurem.

6.2.7. Välte akustiliste tunnuste vaheline kompenseerimine

Artiklis [P8] püütakse multinominaalse logistilise regressioonimudeli abil kirjeldada väldet akustiliste tunnuste (häälikukestused, põhitoon ja vokaalikvaliteet) funktsioonina (vt tabel 2 lk 36). Materjaliks on 1716 kahesilbilist sõna eesti keele spontaanse kõne foneetilisest korpusest. Mudelist selgub, et nii esimese ja teise kui ka teise ja kolmanda välte vastanduses on olulised kõigi segmentide kestused. Lisaks kestusele on esimese ja teise välte vastanduse juures oluline vokaalide kvaliteet, aga mitte põhitoon. Teise ja kolmanda välte vastanduse puhul on aga just vastupidi. Vokaalikvaliteedi analüüsist (vt joonis 10 lk 32) on siiski selge, et rõhulise vokaali kvaliteet on pigem seotud vokaali kestusega ja ei ole jalatasandi välte tunnus. Akustiliste tunnuste vahelist kompenseerumist aga ei tuvastatud: kõik tunnused on selgemalt distinktiivsed aktsentueeritud sõnades ja vähem selgemad deaktsentueeritud sõnades. Tundub, et põhitoon ja vokaalikvaliteet ei ole iseseisvad vältetunnused, vaid on temporaalse varieerumisega kaasnevad nähtused.

6.3. Kokkuvõte

Artiklites [P5] ja [P8] esitatud spontaanse kõne akustiline analüüs tõestas põhitooni olulist rolli eesti sõnaprosoodias. Kui arvestada ka sõnatasandi intonatsiooniga, siis eristab põhitoon teist ja kolmandat väldet mitte ainult laborikõnes, aga ka seotud kõnes. Töös esitatud spontaanse kõne ja tajutestide andmetele tuginedes saab eesti keele kolme välte põhitooni mustreid kirjeldada järgnevalt. Rõhuline silp algab kõigi väldete puhul kõrge platooga, mille kestel põhitoon märkimisväärselt ei liigu. Kõrge platoo lõppeb, kui põhitoon hakkab märgatavalt langema. Selle käänukoha asukoht erineb väldete vahel oluliselt. Esma- ja teisevältelistes sõnades on käänukoht rõhulise silbi lõpu läheduses, kuid kolmandavältelistes sõnades on see juba rõhulise silbi keskel. Kolmandavältelise sõna rõhuline silp peab sisaldama tajutavat kõrget osa ja tajutavat langevat osa. Tajutestid näitavad, et põhitoon võib osutuda teise ja kolmanda välte eristamisel määravaks. Ühelt poolt konflikt teise välte rõhulise silbi lameda põhitooni ja kolmandale vältele iseloomulike silbikestussuhete vahel takistab kolmanda välte tajumist ([P1] ja [P2]), teiselt poolt võib kolmandale vältele iseloomulik langev põhitoon rõhulises silbis esile kutsuda kolmanda välte tajumist ka siis, kui kestussuhted viitavad teisele vältele ([P4]).

Eesti kolmevälte süsteemi kujunemist on seletatud “suure rütminihke” teooriaga, mis sai alguse häälikumuutustest 13. sajandil (Kask 1972; Eek ja Help 1987). Lehiste (2003) on oma välteid käsitleva uurimistöö kokkuvõtteks järeldanud, et eesti keel on muutumas kvantiteedikeelest (tooni)aktsendikeeleks. Artiklis [P7] on esitatud eesti välte akustiliste tunnuste diakrooniline analüüs, kus võrreldi Esimese ilmasõja aegsete salvestuste kõnematerjali tänapäevase eesti keelega. Kuigi kasutatud andmestik on pisut napp kaugeleulatuvate järelduste tegemiseks, tundub, et 20. sajandi alguses oli temporaalsetel tunnustel rohkem eristavat jõudu kui tänapäeval, samas aga on põhitoonitunnuse mõju selle aja jooksul kasvanud. Sellegipoolest, kui siin ka võiks näha muutust suunas, et esimest ja teist väldet eristab kestus ning teist ja kolmandat väldet põhitoon (või kerge ja raske aktsent, nagu pakub Eek 1980b), on see muutus endiselt veel käimas ning teise ja kolmanda välte eristuses on primaarseks tunnuseks siiski temporaalne struktuur.

Pealegi selgus, et põhitooni olulisus teise ja kolmanda välte eristamisel on tänapäeval murdeti varieeruv. Artiklis [P3] testiti suuremat rühma erineva piirkondliku taustaga eesti keelt emakeelena kõnelevaid katseisikuid. Kui Kesk- ja Lääne-Eestist pärit katseisikud olid põhitooni suhtes tundlikud, siis Ida- ja Lõuna-Eestist pärit katseisikud seda eriti ei olnud. Ilmselt on põhjus selles, et ajalooliselt on läänepoolsetel Eesti aladel olnud eesti-rootsi segaasustust (rootsi keeles on tooniaktsendid), aga idapoolsetel aladel on olnud rohkem kontakte vene (kus põhitoon on sekundaarne rõhu tunnus) ning põhja pool soome keelega (mida peetakse klassikaliseks kvantiteedikeeleks, kus leksikaalsel tasandil põhitoonil funktsiooni ei ole). Eesti prosoodiasüsteemile mõju avaldanud keelekontaktide selgitamine vajaks veel põhjalikumat uurimist.

Artiklis [P3] pakuti välja hüpotees, et välte eri tunnused kompenseerivad üksteist: kui kestussuhted on rohkem rõhutatud, ei ole põhitoon nii oluline, aga kui põhitoonitunnus ei ole saadaval (nt kui konsonandikeskses mallis kannab väldet helitu klusiil), on teised tunnused kontrastiivsemad. Spontaankõne analüüsi põhjal see hüpotees siiski kinnitust ei leidnud. Nii publikatsioonide [P5] kui [P8] tulemused näitavad, et kõigi tunnuste eristusjõud on seotud sõna aktsentueeritusega: deaktsentueeritud sõnades, kus põhitoon oli lame, oli ka häälikukestuste ja kestussuhete väldetevaheline kattuvus suurem, aga fookusrõhulistes sõnades olid kõik tunnused väldete vahel kontrastiivsed.

On selge, et eesti vokaalikvaliteet, mida analüüsiti artiklites [P6] ja [P8], ei ole jalatasandi kolmevältesüsteemi tunnus, vaid on seotud häälikukestusega. Vokaalikvaliteedi varieerumine ei ole nii suur, et eesti keele lühikesi ja pikki vokaale eri foneemidena peaks käsitlema. Aga see varieerumine on piisavalt suur, et seda võidaks tajus arvestada vokaali pikkuse hindamisel. Süsteemne vältega seotud konsonandikvaliteedi uurimine on aga eesmärk edasiseks tööks.

Lehiste (1976) on näidanud, et ingliskeelsed kuulajad tajusid sama kestuse korral dünaamilise põhitooniga kõneüksusi pikemana kui monotoonse põhitooniga kõneüksusi ja põhitooni varasema tipuga kõneüksusi pikemana kui põhitooni hilisema tipuga kõneüksusi. Lehiste meelest on see universaalne nähtus maailma keeltes ja viimasel ajal on sellele jälle rohkem tähelepanu pööratud. Eriti vihjavad hiljutised avastused soome ja hiina (aga ka teiste) keelte kohta (Järvikivi *et al.* 2010; Lehnert-LeHouillier 2010; Yu 2010), et kestus ja toon on omavahel seotud nähtused nii kvantiteedi- kui ka toonikeeltes. Ka eesti keele põhitooni ja vokaalikvaliteedi varieerumist võib näha tajutava kestuse ilmingutena. Siiski tundub põhitooni liikumine olevat eesti keeles kestusest iseseisvam kui see on soome keeles.

Samas näitasid artikli [P2] tulemused, et soome ja vene emakeelega katseisikuid ei mõjutanud eesti vältetaju puhul põhitoon, mis on tingitud ilmselt sellest, et katsesituatsioonis mõjutas neid see, kuidas neid on õpetatud eesti välteid eristama. Nad eristasid edukalt eesti välteid rõhulise silbi kestuse järgi. Sama edukad ei olnud aga läti emakeelega katseisikud, keda ilmselt ajas segadusse temporaalsete ja toonimustrite koosmõju eesti keeles, kuna nende emakeeles on need tunnused seotud kahe erineva kategooriaga: pikkuse ja tooniga.

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