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INTERACTIONS BETWEEN SEGMENTAL CONTEXT AND QUANTITY: TEMPORAL PATTERNS OF GEMINATES IN ESTONIAN

Abstract. This study investigates segmental level contextual effects on the acoustic realization of the phonological three-way consonantal quantity contrast. The durational patterns of intervocalic consonants in three quantity degrees are studied as a function of the quality of the consonant and the surrounding vowels. It is generally found in different languages that the main correlate of consonantal quantity or gemination is duration: geminates are longer than single consonants. The durations of underlying segments are also conditioned by their intrinsic properties, i.e., place and manner of articulation, which can interact with quantity. In this paper, the relationship between segmental characteristics and quantity is studied by measuring the durations of different consonants in the three quantity degrees characteristic of the phonetic system of the Estonian language. The results show that in all quantities bilabial consonants are longer than alveolars and velars while obstruents are shorter than sonorants. In Q1 the intrinsic durations of consonants are the most distinctive, in Q2 and Q3 the durations of different obstruents move closer to each other, while the durations of sonorants retain their distinctiveness. Although vocalic context tends to even out these intrinsic characteristics of consonants, they are still somewhat preserved at the level of quantity.

Keywords: Estonian, microprosody, word prosody, three-way quantity, geminates.

1. Introduction

The three-way quantity system is a main feature of Estonian word prosody. Short, long and overlong quantities are distinguished; for example, quantity 1 (short, referred to as Q1) *kabi* [kɑpi] 'hoof, nom.sg', quantity 2 (long, Q2) *kapi* [kɑppi] 'cupboard, gen.sg', quantity 3 (overlong, Q3) *kappi* [kɑpːpi] 'cupboard, part.sg'. Like other prosodic features, such as stress, tone and intonation, quantity operates on speech units larger than single consonants or vowels (Eek, Meister 2003; Lippus Asu, Teras, Tuisk 2013). In order for a quantity feature to function in a language, the timing of articulatory movements associated with quantity must be controlled by a speaker independently of other constraining factors (Ladefoged, Maddieson 1996; Lehiste 1970). Physiologically, however, speech sounds are conditioned by the anatomy and aerodynamic mechanisms of the vocal tract, which are thought to be universal and not controlled by a speaker (Ohala 1983). Thus, depending on the place and manner of articulation, different speech sounds have specific durations, pitch (fundamental frequency, F0) and intensity. These are referred to as intrinsic properties of segments or microprosody (Kirby, Ladd 2016; Lehiste 1970; Vainio, Altosaar 1998; Whalen, Levitt 1995). It should be reasonable to assume that these microprosodic aspects of speech interact with higher level prosody. As a step towards substantiating this hypothesis, the aim of this paper is to study the scope of the interactions between microprosodic durational variations and the realization of the three-way quantity contrast in Estonian.

In the subsequent sections, an overview about general microprosodic patterns in different languages is given first, followed by a short description of Estonian quantity characteristics and the main phonetic properties of Estonian geminate consonants. This forms a background for understanding the general aspects of microprosody and how it could interact with such a prosodic phenomenon as Estonian three-way quantity. Next, in Section 1.3 the aims of this study are presented. Section 2 introduces the material and method, Section 3 presents the results and Section 4 discusses the main findings of this study. Throughout the paper the following abbreviations are used for segments in a disyllabic foot: V1 marks the first syllable vowel, C2 stands for the intervocalic consonant and V2 for the second syllable vowel. Q1, Q2 and Q3 denote the short, long and overlong quantities, respectively.

1.1. Microprosody

Studies about microprosody in different languages have mostly focused on vowels. High vowels are found to be longer and to have a higher F0 than low vowels (Gonzales 2009; Heuft, Portele 1995; Meister, Werner 2006; Whalen, Levitt 1995). The longer duration of low vowels has been explained by a greater displacement of the jaw, which takes more time to realize (Lisker 1974), and the higher intrinsic F0 for high vowels is caused by raising the tongue that in turn raises the laryngeal structures (Honda, Hirai, Masaki, Shimada 1999; Ohala, Eukel 1987; Whalen, Levitt 1995). Some researchers have suggested that intrinsic properties of speech are actually controlled by speakers (Diehl 1991; Jacewicz, Fox 2015; Westbury, Keating 1980). For example, enhancement theory suggests that intrinsic F0 is used for discriminating between different vowel categories (Diehl, Kluender 1989). Pape and Mooshammer (2006) studied the intrinsic F0 in terms of German tense-lax vowels and found no differences between the two categories, whereas speakers tended to increase F0 for lax vowels. In a perception experiment, however, it was shown that pitch was not used for discriminating tense-lax vowel pairs (Pape, Mooshammer, Fuchs, Hoole 2005). For Finnish, Aulanko (1985) has found greater F0 movement for long vowels compared to short ones. Intrinsic segmental duration has also been shown to play a role in the perception of vowel quality. Kouznetsov (2001) found that segment duration is important for discriminating between Russian /e/ and /i/: a shorter duration elicited more responses for /i/. For Estonian, Meister and Werner (2009) have shown that in the case of ambiguous spectral information, vowels with a longer duration were more likely categorized as mid than high vowels, whereas there was no difference in the mid-low pairs.

Less attention has been given to consonants. It has generally been observed that obstruents have longer durations than sonorants (Dimitrieva 2017; Lehiste, Peterson 1959; Lisker 1972; Mendoza, Carballo, Cruz, Fresneda, Muñoz, Marrero 2003), and bilabials are intrinsically longer than coronals and velars (Fischer-Jørgensen 1964; Haggard 1973; Keating, Linker, Huffman 1983; Lehiste 1970; Suen, Beddoes 1974). Articulation of the bilabials involves movements of the upper and lower lips, which can cause greater inertia compared to other consonants articulated with the tongue. The production of velars is also relatively slow due to the less flexible tongue dorsum, as opposed to alveolars, which are produced with the tongue tip (Lehiste 1970).

The properties of speech sounds also depend on the articulatory nature of adjacent segments, i.e. coarticulation. The articulatory movements for different phonemes overlap temporally, and the more the articulators are shared for the sets of articulation, the stronger the overlapping (Fowler, Saltzman 1993). For example, the articulation of vowels involves the tongue, while the articulation of bilabials does not. Thus, there should be less interaction of lingual movements with the production of bilabials compared to, for instance, alveolars, which also use the tongue. Additionally, the regions that are not involved in the formation of a constriction are more likely to exhibit coarticulatory effects, while constrained sounds (e.g., the vowel /i/, alveopalatals) are more resistant to coarticulation. Since velars are articulated with the tongue dorsum, they blend with the surrounding vowels more than constrained alveopalatals, which also have maximal coarticulation on the less constrained /a/ and /u/ (Recasens, Espinosa 2009; Recasens, Pallarès, Fontdevila 1997).

The intrinsic properties of segments vary depending on the articulators involved in their production and the nature of the articulatory movements. Consonants exhibit different durations determined by the place and manner of their production and the properties of their neighbouring segments. Next to these inherent durational properties, a number of languages use duration for distinguishing between length categories. The focus of this paper is on one of these — Estonian.

1.2. Length distinctions

Length distinctions in different languages are generally binary, distinguishing between short and long length categories (see, for example, Idemaru, Guion 2008 for Japanese; Issa 2015 for Libyan Arabic; Neuberger 2015 for Hungarian; Payne 2005 for Italian; Suomi, Toivanen, Ylitalo 2008 for Finnish; Tserdanelis, Arvaniti 2001 for Cypriot Greek). Length can be distinctive for vowels and consonants. Consonants in the long category are also called geminates. However, some languages have ternary length oppositions with short, long and overlong length categories. Three-way length oppositions for consonants are rare, existing in Finno-Ugric languages, such as Estonian (Lehiste 2003; Lippus, Asu, Teras, Tuisk 2013), Livonian (Lehiste, Teras, Ernštreits, Lippus, Pajusalu, Tuisk, Viitso 2008; Tuisk 2012) and Saami languages (Bye, Sagulin, Toivonen 2009 and Türk, Lippus, Pajusalu, Teras 2019 for Inari Saami; Fangel-Gustavson, Ridouane, Morén-Duolljá 2014 for Lule Saami; McRobbie-Utasi 2007 for Skolt Saami).

In late Proto-Finnic short and long geminates occurred at the boundary of stressed and unstressed syllables. Short and long geminates became phonologically distinctive in Estonian and Livonian. In both languages, vowels in the unstressed syllables of disyllabic feet were longer after short geminates, which indicates that changes in word prosody gave rise to the phonological distinction of short and long geminates (Pajusalu 2012). Klumpp, Mazzitelli and Rozhanskiy (2018) point out several Uralic languages that feature consonant gemination: Finnish, Karelian, Votic, Livonian, Kildin Saami, Skolt Saami, Pite Saami, Hungarian and East Khanty. Short and long geminates make a phonological contrast in Estonian and Ingrian. Based on the previous studies on Livonian, Skolt Saami, Inari Saami, North Saami and Lule Saami, these languages also have a distinction between short and long geminates (see Lehiste, Teras, Ernštreits, Lippus, Pajusalu, Tuisk, Viitso 2008 for Livonian; McRobbie-Utasi 2007 for Skolt Saami; Türk, Lippus, Pajusalu, Teras 2019 for Inari Saami; Bals, Odden, Rice 2012 for Noth Saami; Fangel-Gustavson, Ridouane, Morén-Duolljá 2014 for Lule Saami). According to Pajusalu, Uiboaed, Pomozi, Németh and Fehér (2018), who statistically grouped Uralic languages based on their phonological features, contrastive length of consonants occurs in the western Uralic area (Finnic, Saami and Hungarian), where extra-long syllables can have a complex coda, but not in many central-eastern Uralic languages (e.g., Ob-Ugric, Mordvin, Mari, Permic and Samoyed languages).

1.2.1. Quantity in Estonian

Previous phonetic studies have shown that the Estonian three-way quantity distinction is manifested in a disyllabic foot mainly by duration and duration ratios of the stressed and unstressed syllables accompanied by fundamental frequency movement and vocalic quality (Eek, Meister 1997; Lehiste 2003; Lippus 2010; Lippus, Asu, Teras, Tuisk 2013). The opposition of short (Q1), long (Q2) and overlong (Q3) quantity degrees occurs in the primary stressed syllables of a foot. Quantity is carried by the stressed vowels (vocalic quantity; Q1 [sɑte] 'fall-out, nom.sg' — Q2 [sɑːte] 'broadcast, nom.sg' — Q3 [sɑːːte] 'haystack, part.pl'), consonants at syllable boundary (consonantal quantity; Q2 [sɑtte] 'sediment, nom.sg' — Q3 [sɑtːte] 'sediment, gen.sg') or by a combination of both (Q2 [sɑːtte] 'get, 2nd pers.pl' — Q3 [sɑːtːte] 'broadcast, gen.sg'). The unstressed following syllables do not have a distinctive length contrast (Viitso 2003). However, the phonetic length of a vowel in the second syllable depends on the preceding syllable: it is half-long after a short syllable and shortened to a great extent after an overlong syllable due to the length of the previous syllable (Lehiste 1960; 2003). Besides, in perception, the unstressed second syllable plays an important role in distinguishing between Q2 and Q3 (Eek 1980; Eek, Meister 2003; Lehiste 1971).

Quantity phenomena can interact with phrase-level prosody. Asu, Lippus, Teras, Tuisk (2009) studied the temporal and tonal characteristics of Estonian quantity in spontaneous speech taking into account the position of a word in an utterance and accentuation. They found that in non-accented words the duration ratios of V1/V2 were not as stable as in accented words. The durations of V1 and V2 were the shortest in the phrase-initial position, longest in the phrase-final position, and in-between in the phrase-medial position. Thus, word-level prosody can interact, on the one hand, with segmental-level microprosody, and on the other hand, with phrase-level prosody.

1.2.2. Estonian geminate consonants

The consonant inventory of Estonian comprises 17 consonant phonemes as shown in Table 1 (Asu, Teras 2009). All of them except /v/ can occur in three quantity degrees between the first and the second syllable of a word. Consonant quantity is not contrastive word-initially (Lehiste 1966).

Table 1

The consonant inventory of Estonian (Asu, Teras 2009)

	Bilabial	Labio-dental	Alveolar	Post-alveolar	Palatalized	Palatal	Velar	Glottal
Plosive	p		t		t^j		k	
Nasal	m		n		n^j			
Trill			r					
Fricative		f v	s	ʃ	s^j			h
Lateral			l		l^j			
Approximant						j		

The articulatory characteristics of Estonian sonorant consonants have been studied by Eek (1970a; 1970b; 1971a; 1971b; 1971c) and a comparative study has later been carried out by Meister and Werner (2015). They have found that compared to single consonants, geminates are produced with a greater contact area between the tongue and palate and by a greater stiffness of the muscles. However, no clear three-way distinction in the articulatory movements was found in the studies. There were differences between consonant classes, though: The biggest contact area between the tongue and the palate was claimed for /r/, then /l/ and the smallest contact for /n/. In conclusion, Eek (1970) states that in the case of Q3 geminates, the first component of the geminate is tense (produced with a greater muscular effort), while for Q2 geminates the first component is lax. The difference between Q1 and Q2 geminates is made by durational properties, and Q3 involves faster movements.

Türk, Lippus and Šimko (2017) studied the articulatory characteristics of Estonian geminates in different vocalic contexts. Their study had an intervocalic /p/ in the context of /ɑ-i/ or /i-ɑ/ and with /t/ or /p/ as the word-initial consonant. Both meaningful and nonce words were used representing all seven possible quantity combinations in Estonian. The results revealed a strong sensitivity to phonemic context in the articulatory manifestation of consonantal quantity. All three quantity degrees were realized by the duration of the lip closing gesture in the /i-ɑ/ context (the greater the quantity, the longer the duration). In the /ɑ-i/ context the lip closing gesture for Q1 was shorter than for Q2 and Q3. Non-systematic variation dependent on the context also emerged for the displacement of the articulatory movements. The displacement of the lip closing movements for the intervocalic /p/ were greater for Q3 than for Q1 and Q2, but only in words starting with /t/. There were no differences in the speed of the movements depending on the quantity distinction. The results of this study point to the necessity of studying quantity characteristics on varied segmental test material.

Acoustically, Eek (1974) has shown that the durations of consonants and the duration ratios of quantities show differences for different consonant classes in read speech. He measured the durations of the consonants /p, m, t, s, l, n, r/ in three degrees of length (see Table 2). The intervocalic consonants occurred in the /ɑ-ɑ/ vocalic context word-initially, word-finally and word-medially. In all quantities, the longest durations were observed for the bilabials /p/ and /m/ and the shortest durations for /n/ and /r/. Q2 geminates were 2 times longer than singletons, and Q3 geminates were 1.4 times longer than Q2 geminates. Consonants with a longer intrinsic duration exhibited a smaller ratio of singletons and geminate consonants, and for single consonants, differences between different consonants were greater than for geminates. The speech material, however, was limited to one test subject and some methodological issues were identified (Eek 1974).

Table 2

Average durations and duration ratios of intervocalic consonants in the three quantities according to Eek (1974)

Consonant	Q1	Q2	Q3	Q2/Q1	Q3/Q2	Q3/Q1
/p/	92	120	189	1.31	1.58	2.06
/m/	84	120	154	1.42	1.29	1.83
/t/	65	132	187	2.03	1.42	2.88
/s/	59	97	178	1.64	1.85	3.03
/l/	52	119	153	2.27	1.29	2.94
/n/	47	122	138	2.61	1.13	2.95
/r/	24	82	107	3.45	1.31	4.51

The study of Lippus and Šimko (2015) showed the importance of segmental context in the acoustic realization of quantity. Their study used the acoustic data of the same material as in Türk, Lippus, Šimko 2017. Lippus and Šimko (2015) concluded that there are complex relations between segmental context and quantity, and sometimes these even outweigh quantity.

1.3. Objectives

The aim of this study is to investigate the relationship between segmental context and quantity. On a segmental level, the duration of different consonants is determined by the place and manner of their articulation. Prosodic features are generally claimed to be independent of such physical reflections of speech mechanics (Ladefoged, Johnson 2014). Therefore, there should be no interaction between microprosodic features and quantity, so the timing of articulatory movements for quantity should not be determined by mechanical constraints. However, the studies of Lippus and Šimko (2015) and Türk, Lippus and Šimko (2017) have shown complex contextual effects on the acoustic and articulatory realization of Estonian quantity, while sometimes the quantity phenomenon is not robust enough to cancel out segmental context effects. In the light of these studies, the current paper aims to provide an analysis of the durational properties of the Estonian three-way quantity distinction as a function of consonant quality and vocalic context. Specifically, the question is asked how and to what extent the intrinsic properties of segments interact with the acoustic realization of quantity.

The effects of speech production are also shown in geminates cross-linguistically, as geminate obstruents are more common than geminate sonorants (Kawahara, Pangilinan 2017; Podesva 2000). Obstruents may be favoured as geminates due to their longer inherent durations and their being more salient in intervocalic position, while sonorants tend to blend with flanking vowels because they are spectrally continuous. The current study investigates whether this is true for Estonian consonants and if so, whether it affects the stability of the three-way quantity distinction.

2. Material and method

The data for this study were collected from the University of Tartu Phonetic Corpus of Estonian Spontaneous Speech (Lippus, Tuisk, Salveste, Teras 2006). The corpus was manually segmented and tagged using Praat (Boersma, Weenink 2017) to provide the acoustic boundaries of words, syllables and segments, as well as information about quantity and voice quality. At the time of data extraction for this study (March 2017), the total duration of the annotated recordings was about 79 hours: ~70 h for dialogues and ~9 h for monologues, all collected during 2006—2017. The recordings used for the study represented 74 speakers (40 male and 34 female, with an average age of 37.8 years for males and 37.1 years for females) who came from different parts of Estonia, but all of whom spoke standard Estonian. Disyllabic words with a phonologically short first syllable vowel (V1) and varying consonant length (short — Q1, long — Q2, overlong — Q3) were extracted and manually checked for phrasal position and possible errors. Thus, CVCV—CVCCV—CVC:CV words from various word classes were chosen for the analysis (see Table 3 for examples). Since the temporal properties of quantity have been shown to vary in different phrasal positions (Asu, Lippus, Teras, Tuisk 2009), test words only in the phrase-medial position of an utterance were used for the analysis.

Table 3

Examples of the test words for three different word structures

CVCV (Q1)	CVCCV (Q2)	CVC:CV (Q3)
saba [sapɑ] 'tail', nom.sg'	*sopa* [soppɑ] 'dirt, gen.sg'	*kappi* [kɑp:pi] 'cupboard, part.sg'
kõne [kɤne] 'speech, nom.sg'	*tunne* [tunne] 'feeling, nom.sg'	*linna* [lin:nɑ] 'town, part.sg'

The data included 1855 words; their distribution is shown in Table 4. The intervocalic consonants /p, t, k, s, m, n, l/ occurred in varying vocalic contexts with eight different phonologically short monophthongs /i, y, u, e, ø, ɤ, o, ɑ/ (missing /æ/) in the V1 position and all five possible monophthongs /i, u, e, o, ɑ/ in the V2 position. The vowels /i, y, u/ were considered as high, /e, ø, ɤ, o/ as mid, and /ɑ/ as low vowels. For each word the duration of each segment was extracted with a Praat script from the annotated TextGrids. The measurements were manually checked for errors leaving out words pronounced with hesitation, background noise, segmental deletion, etc.

Table 4

The distribution of the data by consonant type (C), quantity (Q1, Q2, Q3), V1 height (high/mid/low) and V2 height (high/mid/low)

C	Q1	V1	V2	Q2	V1	V2	Q3	V1	V2	Total
/p/	71	46/0/25	22/1/48	17	4/7/6	11/2/4	29	15/6/8	13/5/11	117
/t/	186	67/117/2	3/0/183	76	28/48/0	30/31/15	170	91/35/44	24/101/45	432
/k/	294	5/8/281	209/0/85	42	28/10/4	31/3/8	83	17/57/9	68/7/8	419
/s/	43	8/6/29	32/8/3	15	0/14/1	1/13/1	55	53/2/0	2/53/0	113
/m/	35	3/18/14	1/3/31	41	37/1/3	2/38/1	10	1/7/2	3/7/0	86
/n/	89	47/32/10	21/22/46	72	67/0/5	6/47/19	211	180/0/31	28/2/181	372
/l/	16	5/11/0	0/14/2	206	14/191/1	1/194/12	94	56/3/35	1/74/19	316
Total	734	181/192/161	288/48/398	469	178/271/20	82/328/60	652	413/110/129	139/249/264	1855

2.1. Statistical analysis

In order to estimate the effects of consonant type, quantity and vocalic context on the duration of the intervocalic consonant, Bayesian generalized multilevel modelling (also called hierarchical or mixed-effects models) was used (McElreath 2016). The models were fit in R with the brms package (Bürkner 2017, version 1.10.0) using Stan (Stan Development Team 2015, version 2.17.2 (http://mc-stan.org/)), which implements Hamiltonian Monte Carlo algorithms and their extension No-U-Turn Sampler (NUTS). With the brms package, Bayesian regression models can be run with a syntax similar to the lme4 package (Bates, Maechler, Bolker, Walker 2014) used for classical statistics (also called traditional or frequentist statistics).

In statistical inference, parameters that describe the characteristics of a population are unknown (e.g., the true mean of the population or the probability of some event). While in the classical approach to statistics these parameters are fixed, in the Bayesian approach the true parameter value can vary randomly and can be assigned a probability distribution. This distribution forms the basic feature of Bayesian statistics and is called a prior distribution, i.e., information that expresses prior beliefs or knowledge about the parameter. The Bayesian approach to statistics puts together the sample data and the prior distribution, and generates a posterior distribution. Sample data is formally expressed by the likelihood function, which is also used in classical statistics: the probability of observing the data given the values of the parameter. The posterior distribution for a parameter value is the outcome of scaling the likelihood and the prior to one, expressing the probability distribution of plausible values of a parameter given the data. In Bayesian inference, there are no p-values, so it is not based on statistical significance and is therefore 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 (this way, a scientific hypothesis can be included in the analysis) and get more information about an effect by providing a probability distribution of plausible values (Gelman, Stern, Carlin, Dunson, Vehtari, Rubin 2013; McElreath 2016; Stevens 2009).

The Bayesian alternative to frequentist modeling has become more widely used in social sciences and has lately been introduced for phonetics (Vasishth, Nicenboim, Beckman, Li, Kong 2018). For the statistical analysis in this paper, a tutorial by Vasishth, Nicenboim, Beckman, Li and Kong (2018) was followed.

The Bayesian approach to statistics in the current paper was chosen in order to better capture and interpret the complex relationships between different variables in interactions because Bayesian statistics provides a probability distribution of the plausible values representing an effect. Thus, it gives an informative quantitative summary of the effect, whereas traditional statistics is based on significance testing and reporting p-values, which give the probability for the true null hypothesis, indicating the chances of being wrong in testing whether or not the event occurs. In addition, while traditional statistics depends largely on sample size, Bayesian statistics is more flexible and deals better with smaller sample sizes. Addition of three-way interactions to the models used in the study narrowed down the number of tokens for each group, which was a further reason for considering the Bayesian approach more suitable.

In the models, weakly informative generic prior distributions (normal distribution with mean 0 and standard deviation 10) were used in order to prevent extreme computational wanderings, avoiding, however, setting too many restrictions (Gelman, Jakulin, Pittau, Su 2008; Gelman, Simpson, Betancourt 2017; https://github.com/stan-dev/stan/wiki/Prior-Choice-Recommendations (2017); Williams, Rast, Bürkner 2018). This choice to include weakly informative priors was motivated by the fact that although the Bayesian approach to statistical analysis has not been used for studying Estonian quantity before, it would not be reasonable to make any assumptions by merely looking at the data at hand. The results in a number of earlier studies vary extensively in absolute durations of consonants as well as in duration ratios (Eek 1970; 1971b; 1971a; 1974; Eek, Meister 1997; Lehiste 1966). In addition, the test material used in these previous studies was relatively restricted (mainly coming from a single test subject). For these reasons, it was difficult to find a good foundation for choosing prior distributions with means based on previous studies.

The model estimates for the parameters are shown in Figures 1, 2 and 3 with marginal effects plots that give an approximation of the change in the response variable when an explanatory variable changes by one unit, while other variables are kept constant (Leeper 2017). The whiskers represent 95% credible intervals. A 95% credible interval shows that the parameter value lies in the interval with a 95% probability, given the observed data.

3. Results

For studying the interactions between segmental context and quantity, the durations of different intervocalic consonants were investigated in the three quantity degrees and in the context of different vowels. The duration of the intervocalic consonant was tested with Bayesian multilevel modelling, where C2 duration was set as the response variable and the explanatory variables were C2 type (levels: p, t, k, s, m, n, l), quantity (levels: Q1, Q2, Q3), V1 and V2 height (levels: high, mid, low). In this study, the focus was on the interactions between the explanatory variables and therefore, three different interaction models were run: 1) C2 type and quantity, 2) C2 type, quantity and V1 height, 3) C2 type, quantity and V2 height. A test subject and a word were added to the models as random factors.

3.1. C2 type and quantity interaction

First, it was studied whether the intrinsic properties of C2 consonants are realized in the case of dif-ferent quantity degrees. The duration ratios of Q2/Q1, Q3/Q2 and Q3/Q1 for different consonants are shown in Table 5.

Table 5

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

The ratios of Q2/Q1 varied the most between different consonants. The greatest difference between Q2 and Q1 was found for /t/ and /n/ (the ratio is 2.1) and the smallest for /l/ (1.4). The differences between Q3 and Q2 consonants were smaller and varied less, the ratios ranging from 1.1 to 1.4, with the greatest for /k/ and /m/ (1.4) and the smallest for /n/ (1.1). The duration ratio for Q3/Q1 was the greatest for /k/ and /t/ (2.6) and the smallest for /l/ (1.8). In general, /k/, /t/ and /n/ tended to show the greatest duration ratios.

The durational differences between different consonants in three quantity degrees were tested with a two-way interaction model with C2 as the response variable and C2 type and quantity interaction as the explanatory term. The Bayesian model estimates for the durations of different intervocalic consonants in the three quantity degrees are presented in the marginal effects plot in Figure 1, where the dots present the posterior means and the whiskers show 95% credible intervals.

The results showed similar tendencies for different quantity degrees; however, in Q2 and Q3 obstruents and sonorants formed separate groups more distinctively. For words with a short intervocalic consonant (Q1), three facts were observed: the longest segments were /p/ and /s/; /k/, t/ and /m/ were shorter; /l/ and /n/ were the shortest with durations similar to each other.

In words with a Q2 geminate, obstruents and sonorants were more distinguished from each other. The longest duration was estimated for /s/, followed by /p/, /t/ and /k/ with similar durations. Considering sonorants, /m/ was the longest, followed by /n/, and /l/ was the shortest.

In the case of words with a Q3 geminate, /k/ and /t/ were longer than /p/ and /s/. Looking at sonorants, the longest was the bilabial /m/; /n/ and /l/ were the shortest. As can be seen in Figure 1, the bilabials /p/ and /m/ were the longest in almost all quantity degrees, while /m/ was closer to the durations of obstruents than to sonorants. The shortest tended to be the alveolar consonants /t/ and /l/. In Q2 and Q3, sonorants were more resistant retaining their intrinsic durations than obstruents, the durations of which moved closer to each other.

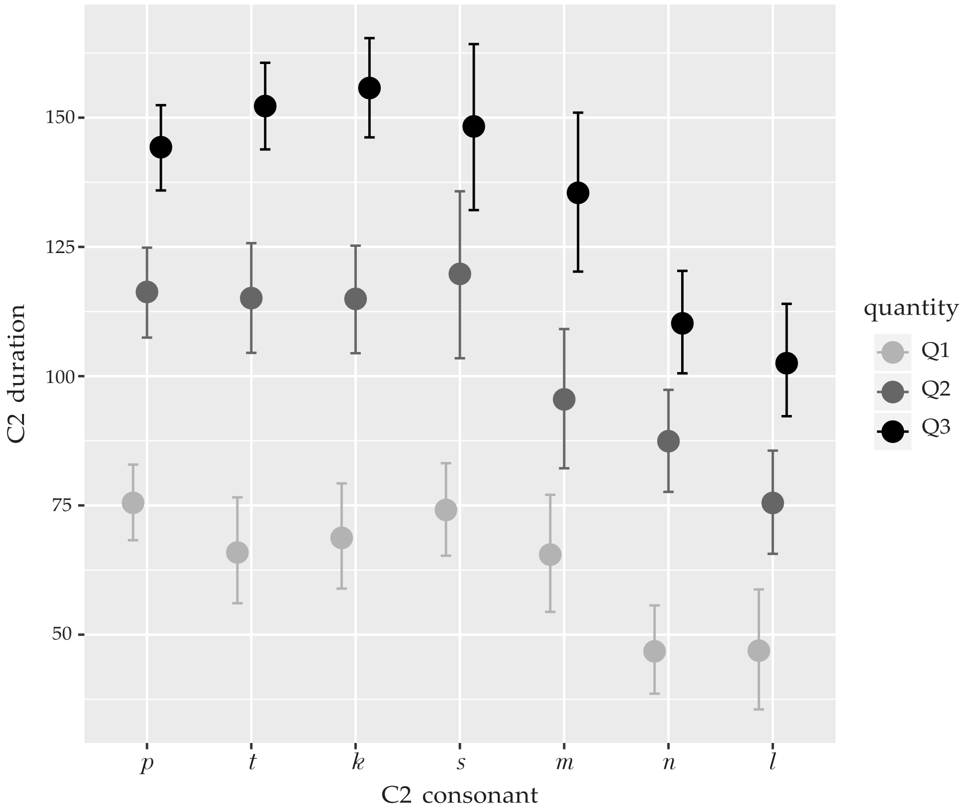

Figure 1. **The effects of C2 type and quantity interaction on C2 duration. The dots present the posterior means and the whiskers show 95% credible intervals.**

3.2. V1 height, C2 type and quantity interaction

Figure 2 shows the predicted values of C2 duration as a function of C2 type, quantity and V1 height interaction. Including V1 height in the interaction showed general patterns of longer C2 durations when the preceding vowel was high or mid rather than low. The differences were the most distinctive for Q2 /t/, /k/, /s/ and /m/, and Q3 /s/ and /l/.

The effects of V1 height somewhat evened out the intrinsic durations of consonants, but obstruent consonants in general were longer than sonorant consonants, and bilabials were longer than other consonants. The following patterns for the durations of different consonants in three quantities were found:

1) in Q1, /p/ and /s/ were longer than /k/ and /t/;
2) in Q2, /p/ was longer than the other obstruent consonants /k/, /s/ and /t/;
3) in Q3, the durations of all obstruent consonants were evened out more, but were also more influenced by the V1 height.

For sonorant consonants, it was found that

1) in Q1, /m/ was longer than /n/ and /l/,
2) in Q2, /m/ and /n/ were longer than /l/,
3) in Q3, /m/ was longer than /n/ and /l/.

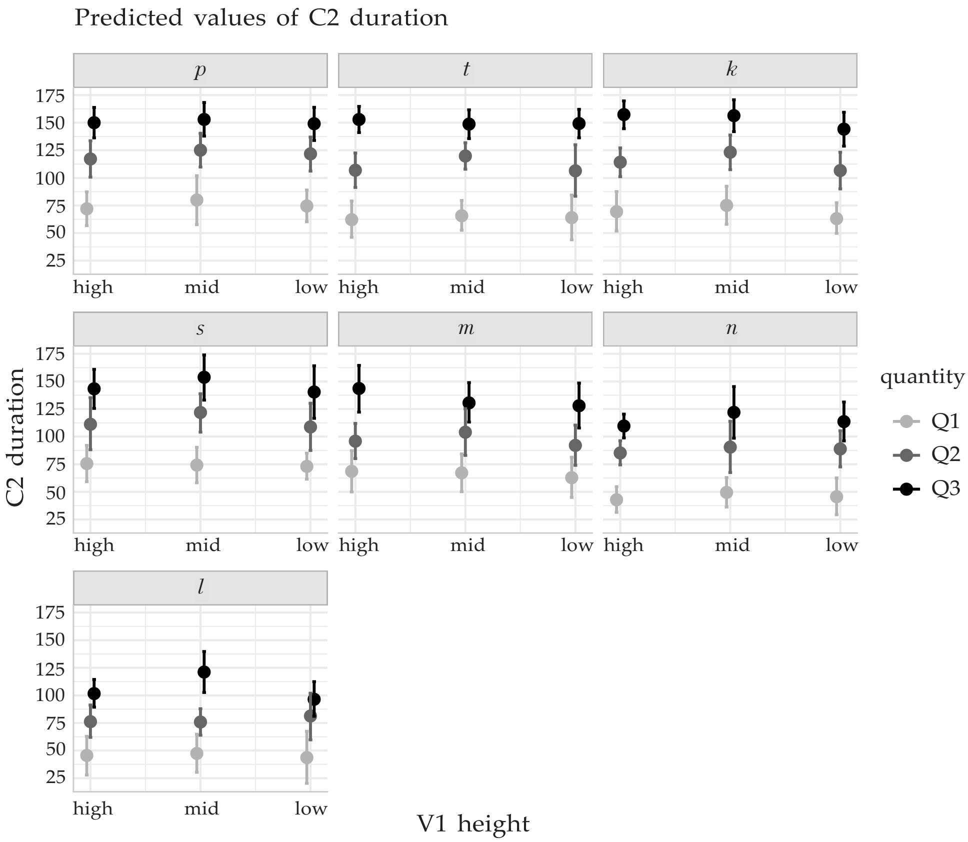

Figure 2. **The effects of C2 type, quantity and V1 height interaction on C2 duration. The dots present the posterior means and the whiskers show 95% credible intervals.**

3.3. V2 height, C2 type and quantity interaction

Next, the durations of C2 consonants were tested as a function of C2 type, quantity and V2 height interaction. This time, the results were more straightforward, and are presented in Figure 3.

In the case of all three quantity degrees, C2 durations were the longest when the following unstressed vowels were high or mid vowels, and the shortest when the following vowels were low. Differences between C2 consonant types were more or less distinct in all quantities. General patterns showed shorter durations for sonorants than obstruents and within those groups, bilabial consonants were mostly longer than other consonant types. For obstruent consonants, the following patterns were found:

1) in Q1, /p/ and /s/ were longer than /t/ and /k/;
2) in Q2, /p/ was longer than /s/, /t/ and /k/;
3) in the case of Q3, the durations of consonants moved closer to each other.

Sonorant consonants had similar patterns in all three quantities: /m/ was longer than /n/ and /l/.

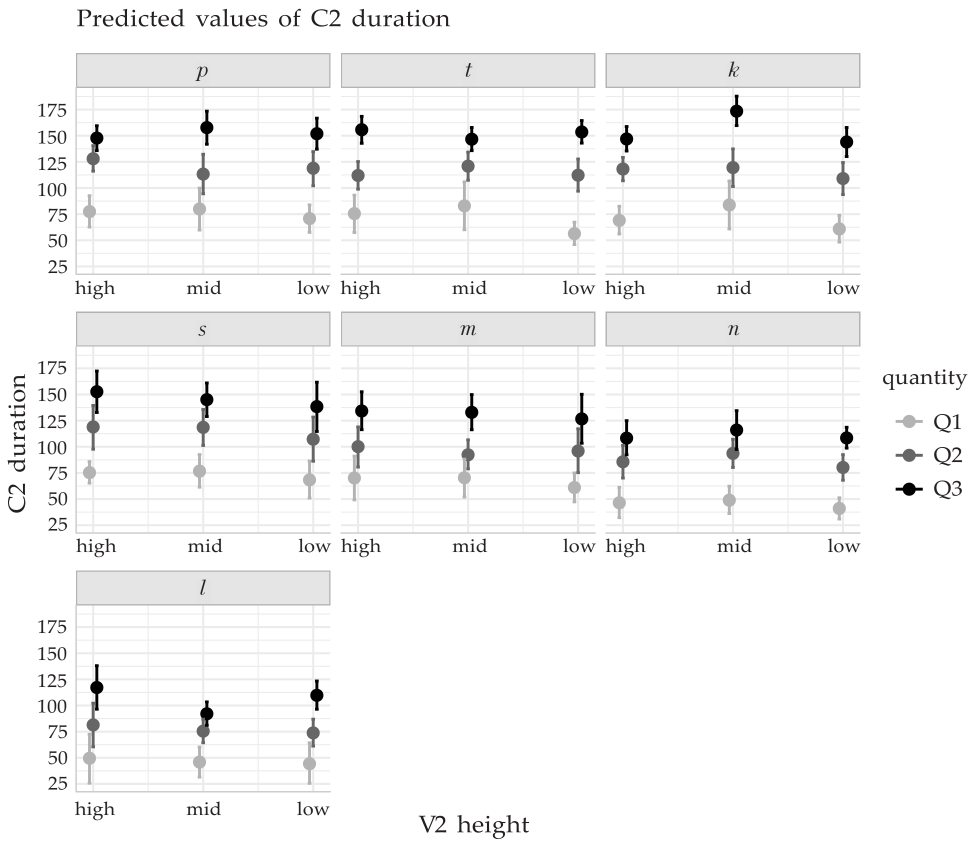

Figure 3. **The effects of C2 type, quantity and V2 height interaction on C2 duration. The dots present the posterior means and the whiskers show 95% credible intervals.**

4. Discussion

The purpose of this study was to investigate the interactions between segmental context and quantity by analysing the durational properties of Estonian short consonants and geminates as a function of the quality of intervocalic consonants and the surrounding vowels. The starting point was that even though quantity is generally considered as something independent and under control of the speaker of a given language, it should not be completely separated from the underlying segmental intrinsic properties that a speaker is unable to control.

The results showed segmental level interactions with higher level prosody. The intrinsic durations of the various consonants were the most different for short consonants, but were also evident for Q2 and Q3. In general, bilabials were longer than alveolars and velars, which corresponds to findings from other languages, e.g., Finnish (Lehtonen 1970), Japanese (Arai, Warner, Greenberg 2007), Cypriot Greek (Arvaniti, Tserdanelis 2000) and Italian (Payne 2005). The production of bilabials involves movements of the upper and lower lips, and this causes more inertia than the movements of the tongue. Since the velar /k/ is articulated by the slower and less flexible tongue dorsum, its duration is also relatively long. These findings suggest that while the speaker is able to control the production of phonological length categories, the movements of articulators for particular sounds are not controlled, and interact with quantity.

The results also showed the effects of manner of articulation. Sonorants in all three quantities were shorter than obstruents, most distinctively in Q2 and Q3. Furthermore, while in Q2 and Q3 the durations of different obstruent consonants had moved closer to each other indicating stronger effects of quantity than of microprosody, the durations of sonorants kept their distinctiveness as a function of consonant quality, especially in Q3. Thus, while sonorants appeared typologically less favoured as geminates, the intrinsic durations of sonorants tended to be more salient in different quantities. This indicates that for sonorants, microprosodic effects may be important in the perception of quantity distinctions, while obstruents, which are less prone to coarticulation with the adjacent vowels, may not need intrinsic duration as an extra cue for length distinctions. This could also result from the fact that spontaneous speech was used as test material. In spontaneous speech there is a tendency for Q2 and Q3 sonorants to shorten. Further research could clarify to what extent Q2 and Q3 consonants can shorten but still be perceived as Q2 or Q3.

Mitterer (2018) argues that geminates could have properties that depend on the language or consonant; for example, some secondary characteristics of geminates are stronger for certain consonants than for others. For Maltese geminates, Mitterer (2018) has shown that /h/ as a short consonant was qualitatively different from its manifestation as a geminate, but /s/ as a geminate did not differ from a singleton /s/. It could be that the same applies for Estonian sonorants and obstruents: The inherent characteristics of sonorants could be stronger than for obstruents, which are more resistant to coarticulation since they are articulated with a more closed jaw than sonorants (Recasens, Espinosa 2009).

Another possible explanation for the differences between obstruents and sonorants in different quantities could be that intrinsically longer obstruent consonants have reached their maximum target durations and cannot lengthen more in greater quantities. For example, in Italian a coronal liquid /l/ lengthened more in the case of gemination than obstruents did (Payne 2005), and in Cypriot Greek stops and fricatives lengthened proportionally less than sonorants (Tserdanelis, Arvaniti 2001). This seems to be true also for Finnish, although the differences are not very big (Lehtonen 1970), but not for Japanese (Arai, Warner Greenberg 2007, who used spontaneous speech data).

For Estonian read speech and with the vocalic context /ɑ-ɑ/, Eek (1974) found that the durations of singletons and geminates also differed less for consonants that had longer intrinsic durations. In the current study, such patterns did not emerge. The bilabials /p/ and /m/ had generally the longest intrinsic durations and the alveolars /t/ and /n/ had the shortest durations in all three quantities, but there was no clear tendency for smaller duration ratios for different quantities in the cases of /p/ and /m/ compared to /t/ and /n/. The differences may come from the nature of the test material used, as the materials in this study as well as in Arai, Warner, Greenberg

(2007) for Japanese were taken from spontaneous speech. However, the duration ratios of Q3/Q2 for nearly all consonants (except for /p/ and /s/) were similar in the current study and in Eek's (1974), showing that the distinction between Q2 and Q3 is relatively stable regardless of the type of speech (read vs. spontaneous) and vocalic context (/ɑ-ɑ/ versus mixed). Additionally, in both studies the effects of the intrinsic durations were the most distinctive for Q1 consonants.

Adding the effects of V1 and V2 height to the C2 consonant and quantity interaction somewhat evened the intrinsic durational differences of C2 consonants. However, obstruents were still longer in duration than sonorants, and bilabials were longer than other consonants. Generally, consonants were longer after high or mid vowels compared to low vowels. Consonants preceding V2 with different heights showed less variation in their durational patterns. Nearly all consonants in all three quantity degrees were longer when followed by high or mid vowels, and shorter when followed by low vowels. V2 height tended to especially influence velars in Q3. High and mid vowels could influence their adjacent segments less due to their more constrained articulation. Note that this has also been shown for vowels and consonants in Catalan (Recasens, Espinosa 2009).

The variation in consonant duration depending on the place and manner of articulation, on the quality of the surrounding vowels and on word quantity seemed to be rather systematic. The results showed that the realization of the three-way quantity distinction is not completely separate from the characteristics of the underlying segmental context. Similar results were also presented in Lippus and Šimko (2015), who found that in some cases, segmental context effects outweighed quantity effects.

5. Conclusion

In this paper interaction between segmental context and prosody was studied by analysing the durations of intervocalic consonants as a function of C2 consonant quality and quantity, and of V1 and V2 quality.

The results showed that the realization of the three-way quantity system was affected by the place and manner of articulation of the intervocalic consonants. In all three quantities, sonorants were shorter than obstruents, and bilabials were longer than alveolars and velars. In Q1, the intrinsic durations of consonants were the most distinctive, and in Q2 and Q3, differences between sonorants and obstruents emerged. The effects of intrinsic durations of obstruents were smaller in Q2 and Q3, while sonorants had generally still preserved their greater distinctiveness. Adding the effects of V1 and V2 height to the interactions of C2 consonant and quantity evened out the effects of the intrinsic durations of C2 consonants, and the interactions between vocalic height and consonant quality then showed universal patterns. After mid vowels, consonants were generally longer than after low vowels, and before high vowels consonants were clearly longer than before low vowels.

In sum, the inherent properties of the segmental context induced by the physical nature of speech production were reflected in the distinction of length categories on a segmental level. Sonorant geminates showed larger differences between the three intrinsic durations compared to obstruents, indicating the formers' less salient nature as geminates. While duration is the primary and universal correlate of gemination, the way in which the intrinsic properties of underlying segments interact with quantity may be consonant-specific. Consideration of the effects of vocalic context showed that the durations of neighbouring segments were adjusted to each other. However, the intrinsic properties of different consonants were still somewhat preserved on a higher level of word prosody.

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ИНТЕРАКЦИИ СЕГМЕНТИРОВАННОГО КОНТЕКСТА И ДОЛГОТЫ: ПРИЗНАКИ ДЛИТЕЛЬНОСТИ ГЕМИНАТ В ЭСТОНСКОМ ЯЗЫКЕ

Статья посвящена взаимосвязям между сегментированным контекстом и долготой. Автора интересует, как реализуется в эстонском языке система трех степеней долготы с согласным в центре в зависимости от качества согласного и окружающих его гласных. В разных языках, в которых присутствует квантитативность согласного, геминаты по длительности дольше одиночных согласных. В то же время, однако, в зависимости от места и способа образования звука варьирует и длительность отдельного сегмента, которая называется собственной долготой звука. В работе анализировалось проявление такого микропросодического варьирования на уровне долготы. Для этого измерялась длительность согласных трех разных степеней долготы и в контекстах с разными гласными. Результаты показали, что во всех трех степенях долготы обструенты (смычные) длительнее сонантов, а билабиальные в большинстве случаев длительнее альвеолярных и велярных. В словах с первой степенью долготы различия согласных по длительности были наиболее ощутимыми. В словах со второй и третьей степенями долготы длительности смычных уравнялись, хотя у сонорных разница в собственной долготе звука сохранилась. Контекст оказал влияние на взаимосвязи расположенных по соседству сегментов: согласные были длительнее, если им предшествовал или следовал за ними гласный низкого подъема. На уровне просодии слова, или степени долготы, в интеракции качеств согласного и гласного собственные долготы согласных несколько уравнялись, но все же различия были заметны.