Electronic offprint from

# BALTIC LINGUISTICS

Vol. 3, 2012

ISSN 2081-7533

BALTIC LINGUISTICS
ISSN 2081-7533
3 (2012), 9–41

# Length contrast and contextual modifications of duration in the Lithuanian vowel system

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Previous studies have shown that the system of contrasts in a given language plays a significant role in determining certain contextual modifications stemming from coarticulation or the acoustic realization of stress. They argue that a limit on coarticulation occurs in cases where a high degree of coarticulation and its corresponding acoustic consequences would decrease the saliency of the relevant contrast. The current study investigates the role of contrastive vowel length in limiting the amount of contextual modification of vowel duration. More precisely, the interaction between vowel length contrast and the stop voicing effect is analyzed. The stop voicing effect results in vowel duration differences depending on whether the following obstruent is voiced or voiceless. The hypothesis is that the presence of vowel length contrast will inhibit the voicing effect, given that contextual variability of duration might blur a contrast based on length. This prediction is tested on Lithuanian, which has an asymmetrical vowel length system: only high and low vowels are contrastive for this dimension; mid vowels are always long. The experimental results show that the voicing effect is stronger for mid vowels, supporting the hypothesis that the presence of a length contrast attenuates the contextual effects on vowel duration.

**Keywords**: phonological contrast, vowel duration, voicing effect, Lithuanian

## 1. Introduction

The vowel inventory of the Baltic language Lithuanian offers a unique system to observe the interaction between phonology and phonetics. Lithuanian makes contrastive use of duration among its vowels, i. e., the language shows a contrast between long and short vowels, a contrast that is well attested in the language through minimal pairs and several morphological alternations. However, as argued in the literature, the inventory is asymmetrical in that not all vowel qualities contrast for duration. There is a *gap* in the Standard Lithuanian vowel system, namely the mid front vowel /eː/ does not have a short counterpart (see section 1.3). This situation lends itself to an investigation of the effects of contextual modification of vowel duration, i. e., low-level phonetic changes in duration, in relation to the asymmetrical use of phonemic duration within the vocalic system. This study explores the interaction between vowel length contrast and the stop voicing effect, i. e., the tendency for vowels to be longer before voiced stops than before voiceless ones. The hypothesis is that the presence of vowel length contrast will inhibit the voicing effect, given that contextual variability of duration might blur a contrast based on length. This prediction is tested on Lithuanian, which has an asymmetrical vowel length system: only high and low vowels are contrastive for this dimension; mid vowels are always long. We expect these differences in length contrast to correspond with differences in the degree of the voicing effect.

Phonological contrast has been shown to affect certain phonetic patterns. A number of studies have investigated the role of contrast in the phonetic realization of segments or its components, focusing mainly on how the system of contrasts of a given language can limit the extent of coarticulation found in that language (e. g., Öhman 1966, Clumeck 1976, Lubker & Gay 1982, Manuel 1990, Manuel & Krakow 1984, among others). Manuel (1999) presents a comprehensive review of this body of work. The primary finding is that the patterns of overlap in time between articulatory commands for adjacent segments are influenced by speakers' efforts to maintain distinctions among segments (Manuel 1999, 180). The presence of a phonological contrast might condition the effects of coarticulation, in most cases by limiting them but also by enhancing them (as in the case of anticipatory lip rounding, see Lubker & Gay 1982). Previous work argues that this limit occurs in those cases where a high degree of coarticulation and its corresponding acoustic consequences would decrease the saliency of the relevant contrast, resulting in confusion of contrastive sounds (Manuel & Krakow 1984, Engstrand 1988, Manuel 1999). Hayes (1995) puts forward the same functional motivation for languages where the presence of contrastive length limits the use of duration as a cue to stress. Given the communicative nature of language, speakers might be expected to exercise some effort to ensure that the acoustic consequences of the articulatory gestures remain distinct (e. g., Martinet 1952, Lindblom 1986, Lindblom and Engstrand 1989, Stevens 1989).

## 1.1. Effects of contrast on coarticulation and on acoustic cues to stress

Research on the role of systems of contrast in limiting or determining coarticulation has primarily focused on (but has not been restricted to) the behavior of vowels. Different dimensions of contrast such as vowel nasality and vowel quality have been analyzed in relation to the hypothesis that phonological contrast can influence the specific patterns of coarticulation in a given language.

Anticipatory contextual nasalization of vowels results when the velum lowering gesture for a nasal consonant starts before the oral closure is achieved. This leads to nasalization during the production of the preceding vowel. In this case, the relevant endangered contrast is between nasal and oral vowels. Thus, the prediction is that, all else being equal, a language with contrastive nasal vowels will restrict the amount of velum lowering during neighboring vowels more than a language without such a contrast. Cohn (1993) reports a greater degree of contextual vowel nasalization before a nasal consonant in English, which lacks a nasality contrast in vowels, than in French, a language with a nasal-oral vowel contrast. In order to avoid contextual nasalization of an adjacent vowel, the velum lowering gesture should be executed only during the oral closure. Consequently, this timing pattern could lead to partial denasalization of the nasal consonant. Herbert (1986) reports that this timing pattern is only found in languages with contrastive nasal vowels suggesting that partial denasalization of the stop is induced by the requirement to maintain a distinctive nasal-oral vowel contrast.

Interestingly, the French oral-nasal contrast for vowels is not present for all its vowel qualities. The high vowels /i, y, u/ do not have a nasal pair. Some previous studies on French nasalization have considered only oral vowels that have nasal counterparts (Clumeck 1967, Cohn 1993). However, Spears (2006) and Delvaux (2000) compared the degree of nasalization in French for vowels with a nasal-oral contrast and for vowels without such a contrast. Spears (2006) examined the amount of nasalization for the high vowel /i/, which lacks a nasal counterpart. This oral high vowel is expected to show more coarticulation for nasalization than vowels that have a contrast for nasality, given the assumption that coarticulation is suppressed to preserve the oral-nasal distinction. Spears measured the amount of nasalization in the oral vowels /i, ɛ/ when followed by a nasal consonant and when followed by an oral stop, and in the nasal vowel /ɛ̃/ word-finally. Taking a formant-like bandwidth between F1 and F2 as an indicator of nasalization, Spears' study obtained the following statistically significant results: (i) more /i/ + nasal tokens show signs of nasalization than /ɛ/ + nasal tokens, and (ii) the duration of nasalization is longer and present in a greater percentage of the vowel for the /i/ + nasal tokens than in the /ɛ/ + nasal tokens. These results indicate that /i/ undergoes nasalization to a greater extent than /ɛ/. But note that Spears found that /ɛ/ + nasal tokens do get some nasalization, i. e., nasalization is not totally suppressed for this vowel. Similar results are reported in Delvaux (2000). Delvaux measured the amount of proportional nasal airflow, defined as the mean proportion of nasal to total airflow and volume, during the production of all the French vowels before a nasal consonant. She found that the amount of nasalization was significantly greater for those vowels that do not have a nasal counterpart than for those that have such a counterpart. To recapitulate, French shows an asymmetry with respect to its contrast in nasality for vowels. All oral vowels except for /i, y, u/, have a nasal counterpart. French has traditionally been described as a language with a very restricted amount of contextual vowel nasalization. The presence of a nasal-oral contrast for vowels in the system is generally assumed to be responsible for this restriction. However, as Spears and Delvaux show, nasal coarticulation is greater for those vowels that do not have a paired nasal vowel. Thus, within the system, nasal coarticulation affects vowels differently depending on their contrastive status.

Consonant-to-vowel (C-to-V) coarticulation can result in undershoot of the vowel, affecting, especially, the front-back vowel contrast. A contrast in backness is related to differences in F2 values, for which back vowels tend to have lower values than front vowels. Thus, if a back vowel occurs after a consonant with a high F2 locus, such as a coronal, then the vowel might be undershot and realized with a higher F2, i. e., more front. Flemming (1997) explores the effects of this type of undershoot in four different languages. Two of these languages, Finnish and German, have a contrast between the back round vowel /u/ and the front round vowel /y/. The other two, English and Farsi, lack this contrast. The prediction of contrast-sensitive coarticulation is that, in those languages with a /u/–/y/ distinction, F2 raising of /u/ due to coarticulation with a preceding coronal consonant will be more restricted than in those languages without the contrast. This follows from the fact that the main difference between /u/ and /y/ is that the F2 values for the latter are higher, and consequently, contextual raising of F2 for /u/ will decrease the distinctiveness between these two vowels. Flemming's results confirm this prediction: Finnish and German show a smaller degree of F2 variation in the context of coronal consonants than English and Farsi. Contextual fronting is restricted in those languages where it would obliterate a front-back contrast.

Relatedly, Choi (1995) investigated vowel production patterns in Marshallese, a language that lacks a front-back vowel contrast. He found that the vowel qualities of backness and rounding are determined mainly by the surrounding consonants. That is, the F2 trajectories for the Marshallese vowels depend on the F2 locus values for their neighboring consonants. This situation is opposite to what Flemming found for Finnish and German, where there is a back-front contrast in the vowel system. In Marshallese, the absence of a vowel contrast in backness allows for a greater degree of C-to-V coarticulation.

Another example of the interaction between contrast and phonetic patterns is found in the realization of stress. The main acoustic correlates of stress are changes in F0, duration and amplitude, which seem to be employed on a language-particular basis (Lehiste 1970). Berinstein (1979) conducted an experiment testing the hypothesis that for a language with contrastive vowel length, duration will be the least important cue to stress. She found that in the Mayan language, K'ekchi, where vowel length is contrastive, production of stress is primarily cued by changes in F0, increase in intensity and changes in vowel duration, with changes in fundamental frequency being the strongest correlate of stress. Furthermore, Berinstein's results for K'ekchi show that vowel duration does not have any effect on the perception of stress in this language. On the other hand, a language related to K'ekchi, Cakchiquel, which does not have contrastive vowel length, uses vowel duration as its primary cue to stress (Berinstein 1979).

Similarly to K'ekchi, Ondráčková (1962) found that Czech, a language with contrastive vowel length, does not make use of duration changes as the main correlate of stress. Hayes (1995) further notes that languages with contrastive vowel length tend to avoid using duration as a cue to stress. As Hayes points out, this is expected given that use of duration to cue stress would 'obscure' the contrastive distinction between long and short vowels. This is related to the fact that length contrasts rely on duration to signal the distinction between long and short elements.

Summarizing, previous studies have shown that phonological contrast can play a role in determining the realization of certain production patterns that might obliterate the distinction among contrasting elements. Most cases come from the interaction between coarticulation and contrast, where articulatory timing patterns might be determined by the presence of a given contrast. Also, the cross-linguistic acoustic realization of stress seems to be restricted by the occurrence of certain contrasts (e. g., vowel length contrast) in any given language[1].

### 1.2. Contrastive vowel length and the voicing effect

This study examines the influence of contrastive vowel length on a contextual pattern that modifies vowel duration, namely the stop voicing effect. The voicing effect makes reference to the observation that vowel duration tends to be shorter before voiceless stops than before voiced ones. This effect has been noted for obstruents in general but here, we focus on the effect due to a following stop. The voicing effect, i. e., the tendency to differentiate vowel duration according to the following consonant voicing, has been attested in numerous languages, such as Dutch, English, French, German, Hungarian, Icelandic, Italian, Korean, Norwegian, Russian, Spanish and Swedish (Chen 1970, Crystal and House 1988, Laeufer 1992, among others; see Hussein 1994 for an overview of relevant studies). A number of factors have been identified as influencing the degree of the voicing effect within a given language. Some of these include word size, inherent vowel

[1] Similarly to the present study, the studies discussed in this section are concerned with the magnitude of the coarticulatory effects and do not directly address the temporal properties of coarticulation. However, the basic assumption regarding these temporal properties is that more coarticulation is found where the relevant gestures have more temporal overlap. For example, in the case of nasal coarticulation, the end of the vowel would display more coarticulation than the beginning given its adjacency to a following nasal consonant.

duration, place of articulation of adjacent consonant, syllabic affiliation of following consonant, stress, speech rate, and position of the word within the utterance (Klatt 1973, Port 1981, De Jong and Zawaydeh 2002, and references therein). As Laeufer (1992) points out, the voicing effect can be masked if all of the above factors are not controlled for. Furthermore, there is another group of factors that, being language-specific, contribute to the cross-linguistic differences of the voicing effect. This group includes the precise way in which the voicing contrast is realized (Kohler 1984), the language rhythm (Port et al. 1980) and the presence or absence of contrastive vowel length in the language (Keating 1985). Focusing on this last factor, there are claims in the literature that the presence of contrastive vowel length in the language attenuates the voicing effect. Keating (1985) reports that differences in vowel duration according to obstruent voicing are practically non-existent in Czech, a language with contrastive vowel length (based on Keating 1979). She further argues that these results from Czech are expected given that vowel duration could be 'reserved' for the length contrast. Similarly, Buder and Stoel-Gammon (2002) point out that the small effect of consonant voicing on vowel duration found by Elert (1964) for Swedish might be explained by the fact that the language has a vowel length contrast.

Unfortunately, despite references to the potential relation between contrastive length and the voicing effect, there appear to be no published reports of experiments testing this claim. Previous studies analyzed languages with length contrasts but failed to separate this factor from other possible factors (see above). In order to analyze the interaction between contrastive vowel length and the voicing effect, it is necessary to isolate contrastive length from other conditioning factors. This challenge may be overcome by measuring the degree of the voicing effect in a language where vowel length is contrastive but only for a subset of its vowel qualities, i. e., a language that has some *unpaired* vowel for the long-short contrast. Then, according to the view presented above, i. e., that the presence of contrastive vowel length attenuates the voicing effect, the vowel without a short (or long) counterpart would exhibit a stronger voicing effect than the vowels in a long-short contrast relationship. This means that within a single system, differences in vowel duration according to obstruent voicing will vary depending on whether a given vowel is contrastive for length or not. Here, the Baltic language Lithuanian becomes relevant because it presents an asymmetrical system for contrastive vowel length. The following experiment analyzes the interaction between the voicing effect and length contrast in this language. Note that the voicing effect is triggered by a subsegmental element, i. e., voicing, rather than by suprasegmental material like in the case of stress cues. Thus, examining the relationship between length contrast and the voicing effect allows us not only to experimentally examine the claims made in previous studies on the voicing effect, but also to broaden our understanding of the interaction between contrast and phonetic patterns.

### 1.3. The Lithuanian sound system

According to descriptions of the language, Lithuanian has a vowel length contrast for all of its vowel qualities except for one, i. e., the mid front vowel (Klimas 1970, Mathiassen 1996). Table 1 shows the vowel inventory for Lithuanian. For clarity purposes, Table 2 includes the orthographic representation of the Lithuanian vowels[2].

*Table 1. Lithuanian vowel inventory.*

| | Front | | Back | |
|---|---|---|---|---|
| High | ɪ | iː | ʊ | uː |
| Mid | | eː | (ɔ) | oː |
| Low | ɛ | æː | a | ɑː |

As can be seen in Table 1, the mid front vowel /eː/ lacks a short counterpart, unlike the high and low vowels, which all contrast in length. This unpaired vowel /eː/ is of special interest since it is expected to

[2] Standard Lithuanian has a tonal distinction that interacts with vowel quality. This tonal system is not fully described here because tone was controlled for in the experiment reported in this paper. For a brief description of the tonal system, see the end of this section.

*Table 2. Lithuanian vowels and their orthographic representations*

| Phonetic symbol | Orthographic representation |
|---|---|
| ɪ | *i* |
| iː | *y, į* |
| eː | *ė* |
| ɛ | *e* |
| æː | *e, ę* |
| a | *a* |
| ɑː | *a, ą* |
| (ɔ) | *o* |
| oː | *o* |
| ʊ | *u* |
| uː | *ū, ų* |

behave differently with respect to the voicing effect compared to the other vowels. The parentheses around the short mid back vowel (ɔ) indicate that this vowel is marginal in the language as it only appears in recent loanwords. Examples include words of Latin and Greek origin and borrowings from English and Russian: *òpera* 'opera', *spòrtas* 'sport', *telefònas* 'telephone', *Òslas* 'Oslo' (Robinson 1973, Mathiassen 1996, Ambrazas 1997). Consequently, some descriptions of Lithuanian include this vowel in the phonemic inventory, while others choose to exclude it and only make reference to its borrowed origin (see Schmalstieg 1969 for the latter position). If the short mid back vowel is not part of the Lithuanian system, its long counterpart /oː/ might be expected to behave like an unpaired vowel for length.

Here a note about the difference in quality between the short-long pairs is necessary, since one might wonder whether those pairs contrast in duration or whether it is mainly a difference in quality. In an acoustic study of Lithuanian vowels, Balšaitytė (2004) found a significant difference in duration between the members of each pair in Table 1. Furthermore, there are morphological alternations between the long and short vowels. For example, [æː] and [ɑː] may result from lengthening in stressed positions of [ɛ] and [a], respectively (Ambrazas 1997, Mathiassen 1996). The example pairs in (1) illustrate this lengthening (data taken from Mathiassen 1996).

(1) Alternations under stress shift in Lithuanian.

| | | |
|---|---|---|
| [ˈn**ɑː**mas] *namas* | *vs.* | [n**a**ˈmʊs] *namus* |
| ‘house.NOM.SG’ | | ‘house.ACC.PL’ |
| [ˈgʲ**æː**ras] *geras* | *vs.* | [gʲ**ɛ**ˈrʊs] *gerus* |
| ‘good.NOM.SG’ | | ‘good.ACC.PL’ |

Further morphological alternations among the short-long paired vowels are found in the language. Some examples are included in (2) (data taken from Mathiassen 1996 and Ambrazas 1997).

(2) Alternations between long and short vowels in Lithuanian.

| | | |
|---|---|---|
| [ˈb**a**lʲtʲɪ] *balti* | *vs.* | [ˈb**ɑː**la] *bąla* |
| ‘get white.INF’ | | ‘get white.PRS.3SG’ |
| [ˈbʲ**ɪ**rʲtʲɪ] *bìrti* | *vs.* | [ˈbʲ**iː**ra] *bỹra* |
| ‘fall.INF’ | | ‘fall.PRS.3SG’ |
| [ˈsʲ**ʊ**nʲtʃʲɛ ] *siuñčia* | *vs.* | [ˈsʲ**uː**sʲtʲɪ] *siũsti* |
| ‘sent.PRS.3SG’ | | ‘send.INF’ |
| [ˈsʲpʲrʲ**ɛ**nʲdʒʲɛ] *sprendžia* | *vs.* | [ˈsʲpʲrʲ**æː**sʲtʲɪ] *spręsti* |
| ‘decide.PRS.3SG’ | | ‘decide.INF’ |

The forms in (1) and (2) show that long and short vowels alternate with each other in morphologically related words. Crucially, [a, ɪ, ʊ, ɛ] alternate with [ɑː, iː, uː, æː], respectively. These alternations indicate that when a vowel changes in its duration, the quality of the resulting vowel also changes to that of the corresponding long or short vowel, showing that changes in length also result in minor differences in quality. This is evidence that at the phonological level, the vowel pairs in question, namely [ɪ-iː], [ʊ-uː], [ɛ-æː] and [a-ɑː], contrast only in length. Thus, length differences represent a phonological contrast, which is accompanied by quality differences in its phonetic realization.

It is also worth noting that numerous studies report that vowel length contrasts tend to be accompanied by differences in vowel quality cross-linguistically (e. g., Lehiste 1970, Abramson and Ren 1990, Rosner and Pickering 1994). The main quality difference between long and short vowels is that the former are usually associated with more extreme formant values than the latter. This results in short vowels occupying a more reduced area of the vowel space compared to their long counterparts (Lehiste 1970). This seems to be related to the fact that the greater amount of duration characteristic of long vowel allows for a more extreme articulation. In fact, the acoustic study of Lithuanian vowels by Balšaityte (2004) presents a vowel space for this language very similar to that reported by Lehiste (1970) for the long and short vowels in Czech. Lithuanian high long vowels are higher than their short counterparts. Also, long low vowels are lower than the short low ones. The same applies to the back-front distinction. This means that long vowels in Lithuanian have more extreme formant values than short vowels, in accordance with previous reports on other languages with contrastive vowel length.

Finally, we should point out that the IPA symbols used to represent the phonetic realization of the Lithuanian vowels, especially for the low front vowels, do not seem to correspond in formant values to the ones typically used for American English. In Balšaityte (2004), the difference in height between [ɛ] and [æː] is smaller than the difference between American English [ɛ] and [æ] reported in Ladefoged (2006) based (see also Peterson and Barney 1952, Hillenbrand *et al.* 1995). That is, the difference in F1 between Lithuanian [ɛ] and [æː] is less than the difference between English [ɛ] and [æː][3]. Thus, it might be the case that the symbols traditionally used for the Lithuanian vowels suggest a greater quality difference than actually exists.

The Lithuanian consonant inventory is given in Table 3 (see Klimas 1970, Mathiassen 1996 for discussion). Palatalization is contrastive in Lithuanian and all the consonants in Table 3, except the palatal /j/, have a palatalized version. In addition, two processes that Lithuanian consonants undergo are relevant for the set-up of the experiment. First, word final obstruents undergo devoicing. Second, there is regressive voicing assimilation in obstruent clusters: the voicing of the

[3] As a reviewer points out, it is impossible to generalize these values to all dialects of Lithuanian or English. My aim here is to argue that, given the limited number of IPA symbols for vowels, the same symbol might be used for vowels in different languages that are in fact relatively distinct in their formant values.

last member of any such cluster determines the voicing realization of any preceding obstruents. Sonorants do not participate in this process, i. e., they do not trigger or undergo voicing assimilation. These two processes must be taken into account when constructing the stimuli since the experiment tests the effect of obstruent voicing, and any context-dependent change in the voicing status of this consonant should be avoided.

*Table 3. Lithuanian consonant inventory*

| | Labial | Labio-dental | Alveolar | Postal-veolar | Palatal | Velar |
|---|---|---|---|---|---|---|
| Plosive | p b | | t d | | | k g |
| Nasal | m | | n | | | |
| Trill | | | r | | | |
| Fricative | | f | s z | ʃ ʒ | | x ɣ |
| Affricate | | | ts dz | tʃ dʒ | | |
| Approxi-mant | | ʋ | l | | j | |

To conclude this section, let us briefly describe the stress and tonal systems of Lithuanian focusing on their interplay with the vowel length distinctions. Stress is contrastive in the sense that it can distinguish between different words, namely between different lexical items, e. g., [ˈgʲɪrʲɛ] *giria* ‘praises’ vs. [gʲɪˈrʲɛ] *giria* ‘forest’, and between different morphological forms, e. g., [nuˈskusʲtʲɪ] *nuskusti* ‘shave.INF’ vs. [nuskusʲˈtʲɪ] *nuskusti* ‘shaven’ (Mathiassen 1996). It should be noted that the Lithuanian vocalic system is not reduced in unstressed positions. The same vowel inventory occurs in stressed and unstressed syllables (Ambrazas 1997). Furthermore, long stressed syllables may contrast in the accent or toneme they bear, either acute with falling pitch or circumflex with rising pitch. Stressed short vowels can only bear a grave tone and, for this reason, accent is not considered to be contrastive for short vowels (Mathiassen 1996). A thorough description of the tonal system in Lithuanian is beyond the scope of this paper. For detailed descriptions and analyses of the Lithuanian tonal system see Kenstowicz (1971) and Blevins (1993), among others. However, it is relevant to note that there is a leveling tendency in the eastern and southern dialects of Lithuanian (Ambrazas 1997).

### 1.4. Goals of the current study

In the light of the Lithuanian inventory, let us precisely state the hypothesis that the current study tests, namely that the long mid front vowel /eː/ will show a stronger voicing effect compared to the other vowels in the system since /eː/ is the only vowel that does not participate in a long-short contrast. For this reason, this vowel is expected to show greater variation in its duration depending on the following obstruent voicing when compared with the other Lithuanian vowels, which do show a contrast for length. Note that /oː/ might also display the same behavior as /eː/, given that its short counterpart /ɔ/ might not be part of the system. The experiment reported here measures the interaction between vowel length contrast and the voicing effect. The results verify the hypothesis that the presence of contrastive vowel length in the system limits the degree of the voicing effect.

## 2. Experimental methodology

### 2.1. Stimuli

A series of nonsense words were constructed according to Lithuanian phonotactics[4]. A native speaker of Lithuanian helped as a consultant and overviewed the creation of these nonsense words. The following criteria were controlled for: syllabic structure, vowel identity and

[4] Nonsense words were chosen because they allow for the study of coarticulation in a systematic way (cf. Boyce 1989, Lindblom 1991, Byrd 1996, among others). More precisely, nonsense words allow us to control for different factors that can have an effect on coarticulation, including surrounding segments, prosodic structure (stress, tone, etc.) and even lexical frequency. The reported result should be found in real words, although the magnitude of the effect could be smaller given other confounding factors that affect vowel-to-consonant coarticulation and vowel duration. For this reason, nonsense words give us the ideal 'testing ground' for our hypothesis, which focuses on a very particular type of coarticulation.

voicing of consonants. Each stimulus consisted of a bisyllabic word of the form ˈ$CV_1C_1.C_2V$, where the first syllable bears the stress. The interest lies in the duration of $V_1$, so this vowel could be any of the vowels in the Lithuanian inventory (see Table 1). The relevant vowel and the following consonant were placed in the same syllable because previous studies have reported a greater voicing effect in cases where the vowel and the consonant are tautosyllabic (Laeufer 1992). Thus, the word medial consonant cluster $C_1C_2$ was formed either by a voiced velar stop [g] followed by a voiced post-alveolar fricative, i. e., [gʒ] for the voiced condition, or by a voiceless velar stop [k] followed by a voiceless post-alveolar fricative, i. e., [kʃ] for the voiceless condition. Given the phonotactics of the language, these are environments where the coda consonants in question retain their voicing. The first consonant and the last vowel in the stimuli were consistently [t] and [a], respectively.

The stress and tonal patterns of the words were kept constant. All target vowels were located in the stressed syllable of the word and all long vowels had a circumflex accent. These were marked using standard orthographic representations known by all the participants. Table 4 shows the 22 stimuli used in the experiment that conform to the criteria just described. Note that the representation of accent is left out from the phonetic transcription because accent was kept constant.

*Table 4. Stimuli used in experiment. This table includes the phonetic transcription and the orthographic representation (< >).*

| | Voiceless condition | Voiced condition |
|---|---|---|
| Long vowels | [tiːkʃa] <tỹkša> | [tiːgʒa] <tỹgža> |
| | [teːkʃa] <tė̃kša> | [teːgʒa] <tė̃gža> |
| | [tæːkʃa] <tę̃kša> | [tæːgʒa] <tę̃gža> |
| | [tɑːkʃa] <tą̃kša> | [tɑːgʒa] <tą̃gža> |
| | [toːkʃa] <tõkša> | [toːgʒa] <tõgža> |
| | [tuːkʃa] <tū̃kša> | [tuːgʒa] <tū̃gža> |

*Continuation of Table 4.*

| | Voiceless condition | Voiced condition |
|---|---|---|
| Short vowels | [tɪkʃa] <tìkša> | [tɪgʒa] <tìgža> |
| | [tɛkʃa] <tèkša> | [tɛgʒa] <tègža> |
| | [takʃa] <tàkša> | [tagʒa] <tàgža> |
| | [tɔkʃa] <tòkša> | [tɔgʒa] <tògža> |
| | [tʊkʃa] <tùkša> | [tʊgʒa] <tùgža> |

The target words were inserted in the carrier sentence *Sakyti* __ *negalima* 'To say __ is not allowed', allowing for control of syntactic and prosodic structure. Each stimulus was repeated 8 times, so that the total number of tokens per speaker was 176. Each block of 22 sentences was randomized with a constraint that the last and first sentences of each block were not the same.

## 2.2. Participants and data collection

Five native speakers of Lithuanian, one male and four females, were recorded. The speakers had been in the United States, in the Los Angeles region, for 5 to 10 years at the time of recording. All the speakers use Lithuanian everyday with their family and friends in Los Angeles and elsewhere, and most of them at work. They often read and write in Lithuanian. All the speakers were recruited at the Lithuanian Sunday School, a community center in Los Angeles, where Lithuanian families bring their children to learn about Lithuanian culture and to celebrate different events and festivities. The speakers described themselves as active members of the Lithuanian community and, as the researcher was able to observe, used Lithuanian to communicate with everybody in the center. It should be noted that these speakers were chosen because they formed a homogenous group regarding their age and educational background—they all had formal instruction in Lithuanian up to the college level—, and because they were Lithuanian-dominant in their daily communication.

Lithuanian displays much dialectal variation. Traditional descriptions distinguish between the Žemaitic dialects in the north-west of the country and the Aukštaitic dialects in the south (see Senn 1945, Schmalstieg 1982, among others for more on Lithuanian dialectal variation). In the present study, we minimize any possible dialectal effect by selecting speakers from the same region of the country. All the speakers are from the eastern cities of Kaunas or Vilnius, and have very similar educational background, i. e., college education. Given this situation, we do not make any claims about other varieties of Lithuanian, and any possible extension of our results to other dialects needs to be independently explored.

A program was created by the experimenter using a Tcl script that displayed the stimulus sentences on a computer screen for the speakers to read and recorded the speakers' utterances using *Wavesurfer*[5]. The target words were presented using the orthographic notation included in Table 4, i. e., all words contained intonation marks as described in the previous section. Although standard Lithuanian orthography does not always include the intonation marks, these might be added for special purposes such as in dictionaries, grammar or textbooks (Mathiassen 1996). As mentioned earlier, all participants had college education in Lithuanian and were familiar with the use of these intonational marks, which did not pose a problem in performing the task. The experimenter controlled the computer and cued speakers for each sentence in order to keep the rhythm constant. More precisely, the experimenter signaled the speakers when to read each sentence so that they would not speed up or slow down during the recording session. The program allowed for repetition of any sentence in cases where the speakers felt they had made a mistake or the experimenter noticed a misread token. The speakers were asked to read each sentence in a colloquial style. The recordings were conducted in a quiet room using a laptop computer and a Plantronics head-mount microphone with USB DSP audio interface, at a sampling rate of 16,000 Hz. Before beginning the actual experiment, the speakers were allowed to practice on a couple of tokens, which were not included in the analysis,

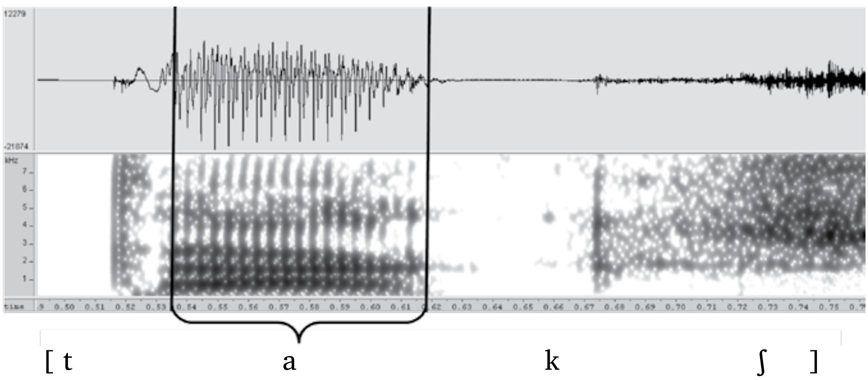
[5] For more info on the Tcl programming language and Wavesurfer see http://www.tcl.tk/ and http://www.speech.kth.se/wavesurfer/ , respectively.

in order to help them get familiar with the nature of the sentences. These practice tokens were the same as some of the stimuli used in the experiment. It should be noted here that speakers did not show or report any trouble reading the nonsense words.

### 2.3. Data analysis

The data was analyzed using the speech analysis program *Wavesurfer*, which displayed the synchronized waveforms and spectrograms used to measure the duration of the relevant segment, i. e., the first vowel in the token words. Before voiceless stops, the target vowel was measured from the onset of the first glottal pulse (the upward zero crossing in the waveform) to the offset of the last glottal pulse in the waveform. Preceding voiced stops, the end of the vowel was determined by a drop in amplitude and a change in waveform shape. For some of the tokens with a following voiced stop, the waveform did not provide a clear ending point. In those cases, the spectrogram was also examined in order to find the timepoint where the formant structure ended. This point was considered the end of the vowel in those tokens. Figure 1 illustrates the vowel duration measurement for a token of the word [takʃa]. The beginning and end points of the vowel have been marked on the graphic representations.

*Figure 1. Waveform and spectrogram illustrating the vowel duration measurement for the word [takʃa].*



The present experiment tests the hypothesis that the presence of contrastive vowel length will inhibit or attenuate the voicing effect of obstruent consonants on preceding vowels. In order to verify this hypothesis for the Lithuanian data set, it is necessary to determine (i) whether long vowels are different in duration from short vowels, (ii) whether there is a stop voicing effect, and (iii) whether the voicing effect is greater for /eː/ than for the other Lithuanian vowels. The first question relates to the presence of vowel length contrast in the language. According to descriptions of the Lithuanian inventory, an effect of length (long or short) should be found for all vowels. The second question addresses the existence of a voicing effect for the data as a whole, namely, whether Lithuanian falls within the set of languages that display a voicing effect. Finally, the third issue directly relates to the hypothesis of the study about the interaction between contrastive vowel length and the voicing effect. If the results from the first and second question show an effect of both length and stop voicing, then it will be possible to test this third question, since for it to hold, contrastive vowel length and the voicing effect must be present in the language.

In order to answer these three questions, a series of one- and two-factor within-subjects repeated measures analyses of variance (ANOVA) were carried out to test the effect of length, vowel identity and stop voicing on vowel duration for the group. Also, a least significance difference (LSD) post-hoc test for vowel identity and a planned means comparison for vowel identity by stop voicing were performed. In addition to analyzing the results for all subjects as a group, individual speakers were analyzed separately for the effect of length and vowel identity through a series of one-factor ANOVAs. Finally, the differences in duration between voiced and voiceless tokens and vice versa were calculated, and the effect of vowel identity on these differences was tested through a two-factor ANOVA and a further LSD post-hoc test for vowel identity. Note that for the repeated measures ANOVAs repetitions per test word were averaged within subjects. For all the statistical tests, the significance level was set at $p < .05$.

## 3. Results

The results are reported according to the effect being tested: length (two possibilities: long or short), vowel identity (eleven possibilities: [iː, eː, æː, ɑː, oː, uː, ɪ, ɛ, a, ɔ, ʊ]), stop voicing (two possibilities: voiced or voiceless), and vowel identity and stop voicing interaction.

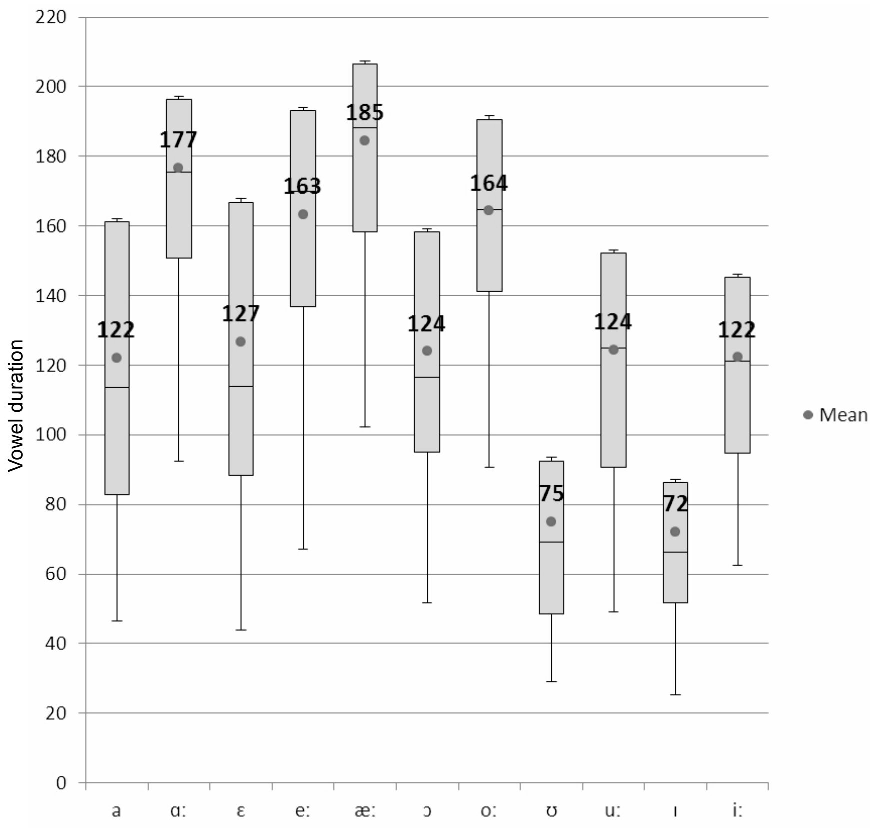
### 3.1. Length effect

The results of a repeated measures ANOVA with vowel duration as the dependent variable and length as the independent variable show that length has a significant effect on vowel duration ($F(1, 4) = 12.28$, $p = .025$), such that long vowels have a greater duration than short vowels. In order to test for possible interspeaker differences, a one-factor ANOVA for length effect was conducted for each subject. The results of these tests show that length is significant for all speakers ($p < .0001$) except for LV, who did not present a significant difference in duration between long and short vowels.

### 3.2. Vowel identity effect

The previous section showed that length has a general effect on vowel duration. However, it is necessary to test whether the relevant vowel pairs ([iː-ɪ, æː-ɛ, ɑː-a, oː-ɔ, uː-ʊ]), are significantly different in their duration. The box plot in Figure 2 shows the average duration (ms) of each vowel and their maximum and minimum deviation for all the speakers pooled together. First, the results of a one-factor repeated measures ANOVA with vowel identity as the independent variable show that vowel identity ($F(10, 40) = 17.25$, $p = .005$) has a significant effect on vowel duration. Second, a post-hoc LSD test for vowel duration gave a vowel-to-vowel comparison for vowel identity. The present study is just interested in the comparison between the members of the long-short pairs. However, the results for the [eː-æː] and [eː-ɛ] comparisons are also reported, in order to evaluate the behavior of unpaired [eː] with respect to duration. Table 5 reports the results of this post-hoc test. Furthermore, in view of the interspeaker differences found for length effect, both an ANOVA with vowel identity as independent variable and a corresponding LSD post-hoc test were carried out for each speaker, in order to observe individual speakers' behavior with respect to differences in durations. These results are also included in Table 4.

*Figure 2. Mean vowel duration (ms) and maximum and minimum deviation for all speakers pooled together*




As Table 5 shows, speaker LV behaves differently from the rest. For most of her long-short vowel pairs, the difference in vowel duration is not significant, indicating that this speaker is not producing a length distinction for these pairs. This behavior reflects the results from the length effect test, which indicated that for speaker LV length was not a significant factor for vowel duration. Given the outlier behavior of speaker LV with respect to length differences, i. e., she does not show a length distinction among the relevant segments, she is excluded from the rest of the statistical analyses. Also notice that another speaker, RK, does not exhibit a difference in duration for the pair [oː- ɔ]. Remember that the status of the short mid back vowel as part of the Lithuanian inventory is debatable and, according to some scholars, it does not belong to the native phonemic system. Finally, it is worth mentioning that [eː] lies inbetween [ɛ] and [æː] as far as duration is concerned. For all the speakers except LV, the value of the mean duration for [ɛ] is less than for [eː] and in turn the value of the mean duration for [eː] is less than [æː], although the difference in these values does not always reach statistical significance.

*Table 5. Results of post-hoc test on vowel duration for vowel identity effect for all the speakers pooled together and also by speaker (* = statistically significant [p < .0001, unless otherwise indicated]; n.s. = statistically non-significant [p > .05])*

| | All speakers | AV | JG | LV | RK | VP |
|---|---|---|---|---|---|---|
| ɑː-a | * | * | * | n.s. | * p = .0006 | * |
| æː-ɛ | * | * | * | n.s. | * p = .015 | * |
| oː-ɔ | * | * | * | n.s. | n.s. | * |
| iː-ɪ | * | * | * | n.s. | * | * |
| uː-ʊ | * | * | * | * p = .043 | * | * |
| eː-ɛ | * | * | * | n.s. | n.s. | * |
| eː-æː | * | * | n.s. | * p = .001 | n.s. | n.s. |

## 3.3. Stop voicing effect

The results of a repeated measures ANOVA with stop voicing as the independent variable show that this factor has a significant effect on vowel duration ($F(1, 3) = 215.95$, $p < .001$). Figure 3 shows the vowel duration (ms) before [g] and before [k] for each speaker (remember that speaker LV is excluded from this analysis). As expected, vowels before the voiced stop are longer than before the voiceless one. This is true for all speakers. Table 6 includes the mean duration for each vowel before [g] and before [k] for all the speakers pooled together.

*Figure 3. Vowel duration (ms) before [g] and before [k] for each speaker.*

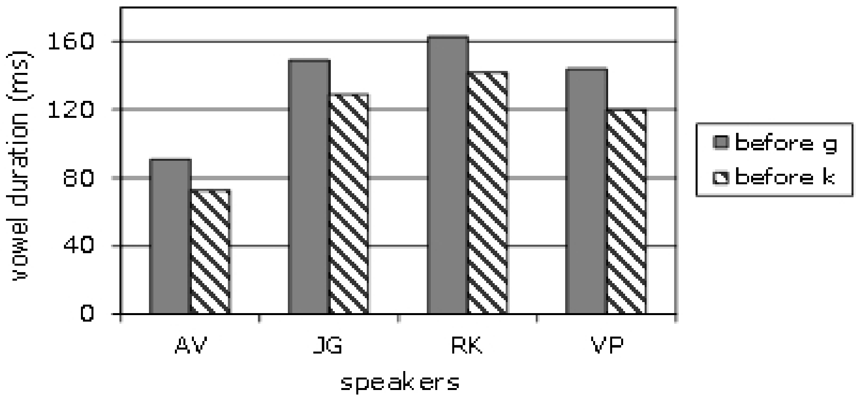



*Table 6. Mean duration (ms) for each vowel before [g] and before [k] (all speakers grouped together, except speaker LV)*

| | Before [g] | Before [k] |
|---|---|---|
| ɪ | 73 | 54 |
| iː | 133 | 112 |
| eː | 178 | 145 |
| ɛ | 119 | 104 |
| æː | 188 | 170 |
| a | 115 | 97 |
| ɑː | 188 | 165 |
| ɔ | 124 | 106 |
| oː | 179 | 151 |
| ʊ | 73 | 57 |
| uː | 130 | 113 |

### 3.4. Vowel identity and stop interaction

This section reports the results of the statistical analyses performed in order to determine whether stop voicing has a different effect depending on the vowel. Ultimately, what needs to be established is whether the stop voicing effect is greater for [eː] than for the other vowels. First, taking vowel duration as dependent variable, a two-factor repeated measures ANOVA for vowel identity and stop voicing as independent variables shows that these two factors have a significant effect on vowel duration ($F(10, 30) = 22.28$, $p = .004$ for vowel identity; $F(1, 3) = 213.35$, $p = .001$ for stop voicing). This is expected from the results of the analyses reported earlier. As for the interaction between vowel identity and stop voicing, this proved to be non-significant. However, this two-factor ANOVA did not establish the degree of the stop voicing effect for *each* of the eleven relevant vowels, and this information is necessary in order to determine whether the voicing effect is stronger for [eː]. For this purpose, a planned comparison of vowel duration means was conducted with respect to vowel identity and stop voicing, for all the data pooled together (except speaker LV). This test compares the duration means for each vowel before [g] with the duration means before [k], providing information about the voicing effect for *each* individual vowel. The results of the means comparison show that the stop voicing effect is significant for the vowels [iː, ɪ, eː, æː, ɑː, oː, ɔ] and non-significant for [ɛ, a, uː, ʊ][6]. However, it is essential to find out not only which vowels are affected by the voicing effect, but also for which vowel the stop voicing has the strongest effect. In order to determine the latter, the F-values obtained from the means comparisons test were ranked. The F-value is a correlate of the effect's strength, i. e., the higher the F-value, the stronger the effect. This means that a ranking from lower to higher F-values correlates with a ranking from

[6] Here, we do not attempt to explain why these two groups of vowels might behave differently with respect to the voicing effect. However, it is worth noting that vowel frequency does not seem to be the cause for the lack of voicing effect for [ɛ, a, uː, ʊ]. Ambrazas (1997) provides phoneme frequency counts in Lithuanian, based on a corpus that contains over 100,000 phonemes occurrences. Regarding their frequency of occurrence, vowels are ranked as follows from most frequent to least frequent: **a** > ɪ > **oː** > **ɛ** > **ʊ** > **eː** > **iː** > **ɑː** > **uː** > **æː** > **ɔ**. The group of vowels that do not show a voicing effect (underlined) is neither the most nor the least frequent in Lithuanian.

vowels less affected by the following obstruent's voicing to vowels more affected by this voicing. Table 7 reports the F-values ranking.

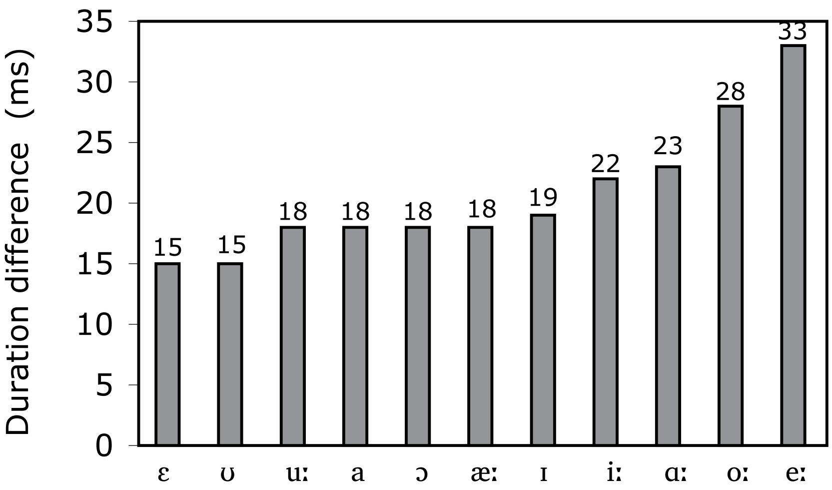
*Table 7. Ranking from lower to higher F-values obtained from the means comparison.*

| Vowel | ɛ | ʊ | uː | a | ɔ | æː | ɪ | iː | ɑː | oː | eː |
|---|---|---|---|---|---|---|---|---|---|---|---|
| F-value | 2.89 | 3.1 | 3.62 | 3.78 | 4.13 | 4.13 | 4.32 | 4.98 | 6.37 | 9.3 | 13.43 |

The ranking in Table 7 shows that [eː] has the highest F-value, i. e., the stop voicing has the strongest effect for this vowel. But, crucially, it is necessary to determine whether the difference in the stop voicing effect among the vowels, more precisely between [eː] and the other ten vowels, is statistically significant. The tests conducted so far cannot provide a response to this issue, since they indicate that the stop voicing effect varies depending on the vowel and that this effect is greater for [eː], but not whether this difference is statistically significant. In order to answer this question, two new variables were introduced: First, the difference in the mean vowel duration before the voiced stop minus each vowel duration before the voiceless stop (i. e., the voiced–voiceless difference variable); second, the difference in the mean vowel duration before the voiceless stop minus each vowel duration before the voiced stop (i. e., the voiceless–voiced difference variable). Note that these two variables were calculated for each vowel, i. e., the means were established by vowel (11 vowels), rather than for all the vowels grouped together. The reason why both variables, i. e., the voiced–voiceless vowel duration difference and the voiceless–voiced vowel duration difference, were included in separate analyses is to control for any possible divergence depending on whether the voicing effect is seen as lengthening or shortening, since here we do not argue one way or another. In what follows, the results for the voiced–voiceless difference are reported. The voiceless-voiced difference results show the same pattern.

The voiced-voiceless difference variable lets us examine whether the variation in duration for each vowel due to the following obstruent's voicing is statistically significant. By subtracting each vowel's duration before voiceless stops from the mean vowel duration before voiced stops, the amount of variation in duration for each vowel is obtained. Now, it is possible to test whether this amount of variation is greater for [eː] than for the other vowels. Figure 4 shows the means of the voiced–voiceless difference, i. e., the mean difference before voiced [g] and before voiceless [k], for each vowel and for all the speakers grouped together.

*Figure 4. Means (ms) for the voiced-voiceless vowel duration difference.*




Note that [eː] has the greatest mean difference, indicating that this vowel shows the highest amount of durational variation due to the voicing of the following obstruent. Also, it is worth noting that in the short-long pairs, the long vowel tends to have a higher mean, indicating that the variation due to the voicing effect is stronger for long vowels in terms of duration difference. This is expected given previous reports in the literature (e. g., Laeufer 1992).

Taking the voiced–voiceless difference as the dependent variable, a one-factor ANOVA was carried out with vowel identity as independent variable. The results show that vowel identity has a significant effect on the voiced-voiceless difference ($F(10, 30) = 2.27$, $p = .040$). The next step is to test whether there is a significant difference in the voiced-voiceless difference between [eː] and the other vowels. A post-hoc LSD test for the voiced–voiceless difference performed a vowel-to-vowel comparison to determine whether the mean for this variable is statistically distinct from one vowel to another. Table 8 reports the relevant results, which are those for the comparisons of [eː] with the other vowels.

*Table 8. Results from post-hoc test on the voiced–voiceless difference for vowel identity effect.*

| Vowels compared | Statistical significance | Mean difference (ms) |
|---|---|---|
| eː-a | * (p = .0012) | 15 |
| eː-ɑː | * (p = .0271) | 10 |
| eː-ɛ | * (p = .0001) | 18 |
| eː-æː | * (p = .0015) | 15 |
| eː-ɪ | * (p = .0027) | 14 |
| eː-iː | * (p = .0170) | 11 |
| eː-ɔ | * (p = .0015) | 15 |
| eː-oː | n.s. | 5 |
| eː-ʊ | * (p = .0001) | 18 |
| eː-uː | * (p = .0017) | 14 |

As seen in Table 8, there is a statistically significant difference between [eː] and all the other vowels except [oː]. I come back to this exception in the discussion section. Remember that the ranking of the F-values from the stop voicing effect for each vowel (Table 7) showed that [eː] had the strongest effect. So, in view of this and the results from Table 8, we can conclude that the stop voicing has the statistically strongest effect on [eː].

As mentioned earlier, the same analyses were conducted for the voiceless–voiced difference variable. The results replicate those obtained for the voiced–voiceless difference and for this reason, no further details are given.

## 4. Discussion

This study examined the role of contrastive vowel length as a potential factor limiting the voicing effect on vowel duration. The data presented here suggest that in fact contrastive length influences the outcome of the voicing effect by inhibiting it in those cases where a length contrast is present. More precisely, our prediction was that in Lithuanian, the long vowel /eː/, which does not have a corresponding short vowel, would display a higher degree of voicing effect compared to the other vowels in the Lithuanian system, which are part of a long-short contrast. As the results reported above indicate, this prediction is supported by the data. Remember that in order to verify the hypothesis at hand, we need to establish (i) whether there is a duration-based contrast, (ii) whether there is a stop voicing effect, and (iii) whether the voicing effect is greater for /eː/ than for the other Lithuanian vowels. Let us comment on these three issues in the light of the experimental evidence.

As the results from the length and vowel identity effect show, long vowels are significantly longer than short vowels for all the vowel pairs, i. e., [iː-ɪ, æː-ɛ, ɑː-a, oː-ɔ uː-ʊ]. This indicates that speakers were making a distinction between the relevant vowels based on duration, as would be expected by the presence of contrastive vowel length in the language[7]. The data analyzed here further show that there is a voicing effect on vowel duration in Lithuanian: vowels were significantly longer before voiced stops than before voiceless ones. Finally, the results from the vowel identity and stop interaction show that the stop voicing effect is greater for [eː] than for the other vowels. This difference was statistically significant for the comparison between [eː] and all the other vowels, except [oː]. The fact that the degree of the voicing effect for [oː] was similar to that for [eː] can be explained by taking into consideration the status of the [oː-ɔ] contrast in the system. As mentioned earlier, some descriptions of Lithuanian challenge the phonemic status of [ɔ], saying that it is only present in borrowed

[7] Note that this contrast is present for all the speakers except LV, who fails to produce some of the relevant distinctions. LV's exceptional behavior might be due to the experimental setting, since LV had more difficulty performing the task than the rest of the speakers.

words. If [ɔ] is in fact not part of the Lithuanian phonological system, then [oː] can be argued to not be part of a short-long contrast. Thus, we would expect this vowel to pattern with [eː] and display a stronger voicing effect than the rest of the vowels[8].

Clearly, the hypothesis is borne out by the experimental results. The voicing effect is maximally strong for the vowel that is not part of a short-long contrast, i. e., [eː] (and potentially [oː]) in the case of Lithuanian. On the other hand, those vowels that have a short or long pair seem to be less affected by the stop voicing. These facts support the claim that we set out to prove, namely that contrastive vowel length interacts with the voicing effect, in that the presence of such a length contrast in a language inhibits the effect. This conclusion agrees with previous findings in languages with contrastive vowel length such as Czech and Swedish, where the voicing effect is practically non-existent or minimally observable (Keating 1985, Buder and Stoel-Gammon 2002). It should be noted that the voicing effect is not altogether blocked by the presence of contrastive length but rather the contextual modification of duration occurs to a lesser extent. Thus, the requirement to maintain a distinct durational contrast is one of several factors which might be at play in relation to the voicing effect. This observation bears on the issue of how strong the requirement to maintain a contrast might be, i. e., how much maintaining a distinct contrast might influence the outcome of contextual variation due, for instance, to coarticulation or the voicing effect. There are (at least) two hypotheses, which may be dubbed the *strong hypothesis*—contrast may block contextual modification—and the *weak hypothesis*—the presence of contrast may result in more or less modification (but crucially some modification) (cf. Manuel 1990). The data presented here support the *weak hypothesis*. We can see that the presence of contrast, rather than acting as a total blocker of the voicing effect, reduces the amount of durational variability due to this effect. Note that the results from French reported in Spears (2006) and Delvaux (2000) lend further support to the *weak hypothesis*, since in their data, vowels contrastive

[8] Bearing on this issue, the results from the vowel-to-vowel comparison for vowel identity (see Table 5) showed that two speakers (LV and RK) did not make a difference in duration between [oː] and [ɔ].

for nasality did get some nasalization but to a lesser degree than those vowels that are not contrastive for that dimension.

Previous studies on the role of contrast in limiting coarticulation have focused on cross-linguistic differences resulting from different systems of contrasts (e. g., Öhman 1966, Manuel and Krakow 1984, Manuel 1990). However, as Manuel (1999) points out, what counts as contrastive varies not only from language to language but also within the elements or segments of a given language. Therefore, differences are expected to be found depending on the language and also the segment in particular. The Lithuanian data show that the voicing effect has a different outcome depending on the vowel it modifies, more precisely, depending on whether the vowel is part of a long-short contrast or not. Thus, this study shows that differences in contrastive length within a single system might result in different contextual modifications depending on the element that is being affected.

The results presented here are relevant not only because they shed light over the relationship between contrastive vowel length and the voicing effect, but also because they suggest that this phonetic effect is sensitive to the asymmetrical system of the language. The voicing effect treats vowels in contrasting pairs differently from vowels that do not have a pair for length ([eː] and possibly [oː]). Vowels that belong to a short-long pair with the same quality are not modified as much by the voicing effect as unpaired vowels. The voicing effect involves a contextual modification of duration and short-long pairs are more resilient to its effects. These facts indicate that contrastive vowel length cannot be assumed to be a property of the whole system or language; otherwise all vowel qualities would be treated alike with respect to this contextual modification. In fact, individual vowels behave differently, suggesting that each vowel must be defined with respect to whether it enters in a length contrast relationship or not. Concluding, this study shows that differences in the relative use of duration in production are in part determined by the phonological structure of the language.

## Acknowledgments

The author would like to thank Rachel Walker and Dani Byrd for detailed discussion of different aspects related to this paper. Thanks also to Abe Kazemzadeh and Jelena Krivokapić for carefully reading the manuscript and for their valuable input. The author would also like to acknowledge the USC Phonetics Laboratory, where the data analysis was conducted.

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