



Singleton and Geminate Stops in Finnish – Acoustic Correlates

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Abstract

The present study examined a variety of acoustic correlates to the stop length contrast in Finnish beyond the duration of the consonant itself. Of interest were the durations of surrounding vowels, the duration of voice onset time (VOT), and the amplitude of the release burst and the following vowel. Results indicated that for geminate stops, VOT is shorter and the amplitude of both the following vowel and the release burst are higher than for singleton stops. Further, long vowels preceding geminate stops are shorter than those preceding singleton stops, although no difference was found for short vowels. Post-consonantal vowel duration does not vary as a function of consonant length, but is affected by the length of the first-syllable vowel. These results agree with data from other languages in some respects, but not in others. It is proposed that this discrepancy arises from the fact that Finnish, despite being stress- or syllable-timed, also has mora-like length features.

Index Terms: Finnish, geminate, duration, fundamental frequency, RMS amplitude

1. Introduction

Stop length distinctions are most readily defined in terms of the duration of stop closure: geminate stops have longer closure durations than singleton stops. However, investigations of singleton vs. geminate stop contrasts in a variety of languages have demonstrated that there are additional correlates to stop length in terms of the duration of adjacent segments as well as other acoustic characteristics of both the stop itself and surrounding segments [1, 2, 3, 4, 5, 6].

In terms of the duration of surrounding segments, a common typological pattern was described by Maddieson [7]: vowels before long consonants are shorter than they are before short consonants; that is, there is an inverse relationship between vowel duration and consonant length. However, this inverse pattern has not been found for all languages (e.g., [8]). Similarly, several studies have demonstrated that Japanese seems to go against Maddieson's typological generalization, as vowels preceding geminates are lengthened rather than shortened [9, 3, 10]. The lack of inverse patterning in Japanese may be related to moraic timing. Mora-timed languages have length contrasts which are more robust than syllable-timed languages [6]. We may speculate that the large singleton-to-geminate ratio for stop duration in Japanese is such a robust perceptual cue that the inverse patterning of the preceding vowel is not needed as a perceptual cue, and so not correlated with stop length. It must be noted, however, that Idemaru [3] found a small inverse effect for *following* vowels in Japanese.

Some researchers have also explored the duration of voice onset time (VOT) in languages with stop length contrasts. Arvaniti and Tserdanelis [11] found that VOT in Cypriot

Greek was significantly longer after voiceless geminate stops than corresponding singleton stops. However, Cohn *et al.* [12] investigated the VOT of singleton and geminate stops for three languages spoken in Indonesia and did not find any apparent VOT differences based on stop length. Thus, like preceding vowel length, VOT also seems to vary in its instantiation cross-linguistically.

Non-durational correlates of geminate stops have also been investigated in the literature. One such non-durational correlate is the amplitude of the surrounding segments. Abramson [2] reported that the amplitude of Pattani Malay vowels following word-initial geminate stops was greater than that following singleton stops. Idemaru [3] found that the amplitude of pre-stop vowels relative to that of post-stop vowels was greater across geminates than across singletons. Additionally, Arvaniti and Tserdanelis found that the burst and aspiration of geminate stops had a higher RMS amplitude than the burst and aspiration of singleton stops [11].

The present work sought to explore some of these correlates for Finnish. Although Finnish is often considered to be either syllable-timed or stress-timed (see [13] for discussion), some have stated that moraic considerations might also be important for a full description of Finnish [14], as the length of both vowels and consonants is contrastive. Considering the possibility of moraic timing in Finnish draws a parallel with mora-timed languages such as Japanese. Indeed, study of these parallels has formed the basis of several studies (e.g., [14, 15]).

With the aim of understanding the acoustic correlates to the length contrast in Finnish, several acoustic measures were examined. Acoustic measures found to correlate with the length contrast in the mora-timed language Japanese were included, as well those found to correlate with the length contrasts in stress- and syllable-timed languages.

2. Method

Three native speakers of the Southern Häme dialect of Finnish (all female) were recruited to participate in the study. Subjects were compensated for their time.

2.1. Materials

In order to test for possible effects of singleton vs. geminate stops on the length and the amplitude of surrounding vowels, a series of non-lexical words was created in which the vowel preceding and the vowel following the stop alternated between short-short, short-long, long-short and long-long. Although the vowel of the second syllable alternated between /i, a, u/, the vowel in the first syllable was always /e/ in order to keep the number of tokens reasonable. Similarly, the beginning consonant of each word was always /s/. A complete list of target words is presented in Table 1.

Singleton Stops					
seka	seeka	seta	seeta	sepa	seepa
sekaa	seekaa	setaa	seetaa	seppaa	seepaa
seki	seeki	seti	seeti	sepi	seepi
sekii	seekii	setii	seetii	sepii	seepii
seku	seeku	setu	seetu	sepu	seepu
sekuu	seekuu	setuu	seetuu	sepuu	seepuu

Geminate Stops					
sekka	seekka	setta	seetta	seppa	seepa
sekaa	seekkaa	settaa	seettaa	seppaa	seepaa
sekki	seekki	setti	seetti	seppi	seepi
sekki	seekki	setti	seetti	seppi	seepi
sekki	seekki	setti	seetti	seppi	seepi
sekku	seekku	settu	seettu	seppu	seepu
sekkuu	seekkuu	settuu	seettuu	seppuu	seepuu

Table 1: Complete list of target tokens collected by stop length.

2.2. Recording

The target words were presented to subjects in a randomized list written in the carrier phrase *Sanoit _____ taas* ('You said _____ again'). Participants were instructed to read each sentence at a conversational rate and volume. Each speaker recorded three repetitions of each word, though only the first repetition is considered below.

2.3. Measurements

Each word was isolated, segmented and annotated using the software program Praat [16]. Segments were isolated as follows: The onset of V1 was placed at the beginning of the first clearly-repeating voicing cycle which coincided with the onset of second-formant (F2) energy. The onset of the intervocalic consonant was placed at the end of voicing; the offset of the intervocalic consonant was placed at the beginning of the stop burst. V2 onset and offset were marked using the same criteria as V1. All vowel onset/offset measures were taken at the zero crossing.

The period between the release of the target consonant and the onset of V2 was divided into two parts. The first section isolated only the burst of the stop, in order to measure its amplitude without the influence of the following vowel. Burst was operationalized as the high intensity energy immediately following the stop. The remainder of the gap between the release of the stop and the onset of voicing was isolated as the second portion, so that it could be added to the burst duration for a complete measure of voice onset time.

The duration of each segment was then measured in milliseconds and the root-mean-square (RMS) average amplitude of the stop burst and V2 was measured in dB SPL.

3. Results

3.1. Durational Correlates

3.1.1. V1 Duration

The duration of V1 was submitted to a 2 x 2 x 2 repeated-measures analysis of variance (ANOVA) with phonological length of V1, V2, and the consonant as within-subjects factors. Unsurprisingly, the duration of V1 showed a main effect of phonological V1 length [$F(1,26)=138.71, p<.001,$

$\eta_p^2=.84$], indicating that long and short vowels were produced contrastively before geminates. Short V1s ($M=87$ ms) were, on average, 100 ms shorter than long V1s ($M=187$), a ratio of 1 : 2.17.

In addition to the main effect of V1 length, a main effect of consonant length on the duration of V1 was also found [$F(1,26)=49.10, p<.001, \eta_p^2=.65$]. Further, the two factors of V1 length and consonant length showed a significant interaction [$F(1,26)=19.72, p<.001, \eta_p^2=.43$], presented in Figure 1. Pair-wise tests on the estimated marginal means indicated that long vowels were significantly shorter when followed by a geminate consonant ($M=173$ ms) than when followed by a singleton ($M=201$ ms) [$F(1,26)=53.72, p<.001$]. However, no significant effect of consonant length was seen for short vowels [$p=.84$].

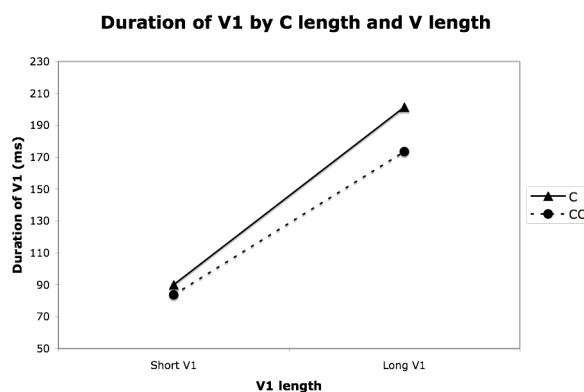


Figure 1: Duration of long and short V1s by consonant length.

Although long vowels before a geminate consonant in Finnish seem to fit Maddieson's [7] typology that vowels before geminates are shortened, the short vowels do not exhibit durational differences due to the length of the following consonant. It thus seems that the inverse relationship between vowel and following consonant is somewhat mitigated by vowel length in Finnish.

Further, these results indicate that Finnish is not similar to Japanese in lengthening vowels before geminate stops. We do not see short vowels (the only type included in [3]) becoming longer before a geminate consonant. Rather, they seem to be unaffected by the following consonant.

3.1.2. V2 Duration

The duration of V2 was also submitted to a repeated-measures ANOVA of the same design used for V1. For V2 duration, a significant main effect of V2 length was found [$F(1,26)=95.95, p<.001, \eta_p^2=.79$], indicating that the long and short vowels in post-geminate, word final position are produced contrastively. Short V2s ($M=84$) were, on average, 110 ms longer than long V2s ($M=194$), a ratio of 1 : 2.31.

No main effect of consonant length was found, indicating that consonant length did not affect the duration of V2. However, there was a main effect of V1 length [$F(1,26)=15.90, p<.001, \eta_p^2=.38$] as well as a significant interaction between V1 length and V2 length [$F(1,26)=12.61, p<.001, \eta_p^2=.33$], shown in Figure 2. Pair-wise comparisons indicated that short V2s were significantly shorter following long V1s than following short V1s [$F(1,26)=47.19, p<.001$]. Long V2s, on the other hand, showed no durational effects based on the length of V1 [$p=.69$].

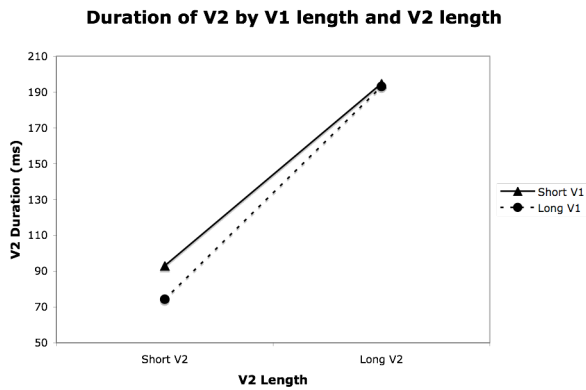


Figure 2: The duration of V2 by the phonological length of V1 and V2.

Thus, short V2s are longer after a short V1 and shorter after a long V1. It appears that V2s undergo some sort of inverse lengthening or shortening in relation to V1, although the cause of this pattern is not immediately clear from the present study.

3.1.3. Voice Onset Time

VOT was computed by adding the burst duration to the remainder of the gap between the burst and the onset of voicing. These values were then submitted to a repeated-measures ANOVA of the same design used above. Singleton consonants were seen to have VOTs which were significantly longer ($M=22.4$ ms) than the VOTs of geminate consonants ($M=19.5$ ms) [$F(1,26)=15.63$, $p=.001$, $\eta_p^2=.38$], as indicated in Figure 3. Further, the results indicated that VOT was also longer if either V1 or V2 was long [$F(1,26)=7.44$, $p=.01$, $\eta_p^2=.22$ and $F(1,26)=7.79$, $p=.01$, $\eta_p^2=.23$, respectively]. However, the effect of vowel length did not interact with consonant length, indicating that the effects of vowel length and consonant length were not additive.

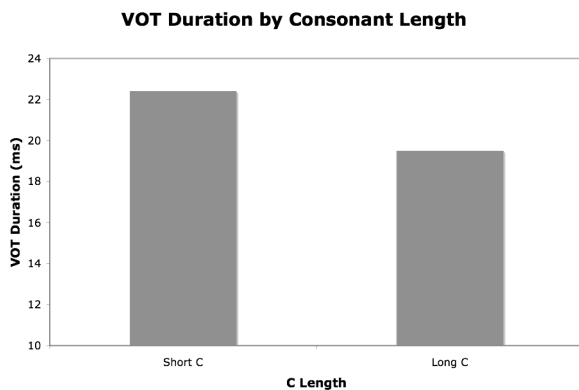


Figure 3: Duration of VOT following short and long consonants.

Thus, the VOT of singleton and geminate stops varies in Finnish, contrary to Cohn *et al.*'s findings for three Indonesian languages [12], but similar to Tserdanelis and Arvaniti's results on Cypriot Greek [11]. However, recall that VOT in Cypriot Greek was significantly longer after geminate stops rather than singleton stops, the opposite of the pattern found in Finnish. Note, however, that with an average difference of only 3 ms (below the boundary for a just noticeable difference of roughly 10 ms [17, 18]) it is unlikely that VOT would serve as a perceptual cue to the length of the stop consonant in Finnish.

3.2. Non-duration Correlates

3.2.1. Amplitude of V2

The amplitude of V2 was also submitted to a repeated-measures ANOVA of the same design used above. Significant main effects of both consonant length [$F(1,26)=6.70$, $p=.016$, $\eta_p^2=.21$] and V1 length [$F(1,26)=8.32$, $p=.008$, $\eta_p^2=.24$] were found, with V2 having a higher amplitude following long consonants ($M=65.84$ dB vs. 64.76 dB) and a lower amplitude after long V1s ($M=64.84$ dB vs. 65.76 dB), respectively. Further, a three-way interaction between V1 length, V2 length and consonant length was found [$F(1,26)=4.44$, $p=.045$, $\eta_p^2=.15$]. The effects of the interaction were such that consonant length had no effect on the amplitude of V2 if V1 was short and V2 was long. In all other cases, long consonants resulted in a second vowel with a higher amplitude than those following a singleton consonant. Results for each vowel length combination are presented in Figure 4.

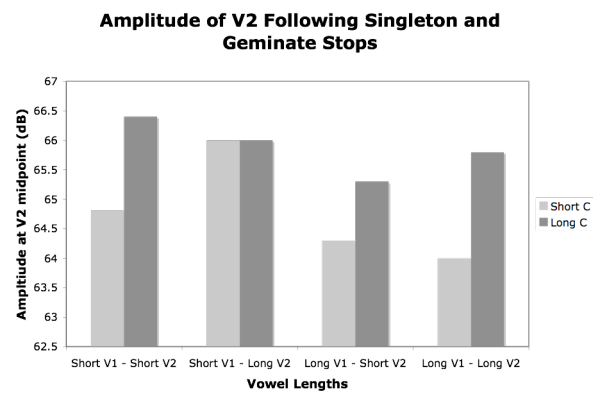


Figure 4: Effect of consonant length on V2 amplitude.

The greater amplitude of the vowel following a geminate stop is compatible with Abramson's findings for Pattani Malay which showed that vowels following geminate stops had higher amplitudes than those following singleton stops [2]. This finding is also partially compatible with Idemaru's finding that geminates cause an increase in the amplitude of surrounding segments [3], although for Japanese it is pre-consonantal amplitude which is increased rather than post-consonantal amplitude.

However, the finding here is slightly more complex than that in previous studies, given that vowel length also seems to play a role in some cases. If this higher amplitude is in fact a property of the consonant itself, one would expect it to be present at the release. For this reason, the release bursts for singleton and geminate stops were considered.

3.2.2. Amplitude of the Burst

The amplitude of the burst in decibels was submitted to a repeated-measures ANOVA of the same design used above. The test indicated that the release bursts of geminate consonants ($M=57.0$ dB) were significantly louder than the release bursts of singleton consonants ($M=55.5$ dB) [$F(1,26)=8.28$, $p=.008$, $\eta_p^2=.24$]. These results are presented in Figure 5. No other main effects or interactions were found for the amplitude of the burst.

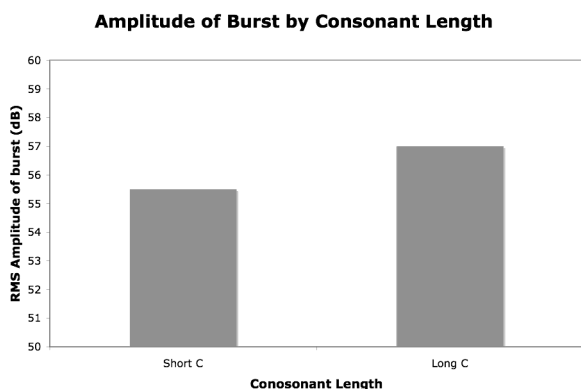


Figure 5. *Amplitude of stop release bursts by consonant length.*

4. Discussion & Conclusion

Contrary to the prediction that Finnish might look like mora-timed languages such as Japanese in its realization of a stop length contrast, no evidence of this was found. Unlike Japanese (e.g. [10]), vowels preceding geminate consonants were not seen to lengthen. However, Finnish also differs from the typologically-common pattern in which vowels prior to long consonants shorten. Although long vowels in Finnish did shorten before geminates, the duration of short vowels was not affected by the length of the following consonant.

Post-geminate vowels in Finnish were also not affected by the length of the consonant, unlike Japanese (e.g., [3]), where the duration of the following vowel showed an inverse relationship with the length of the consonant. Post-geminate vowels in Finnish, however, entered into an inverse relationship with the length of the pre-consonantal vowel. This finding was unexpected and warrants further investigation into the possible influence of prosodic features, such as word-level durational patterning.

The fact that VOT is longer after singleton stops in Finnish is perhaps not surprising in light of some other languages which show variation in VOT duration based on stop length, but it also seems that this sort of variation is not universal. In some languages, no variation in VOT is found for singleton and geminate stops (three languages of Indonesia [12]), while in others (Cypriot Greek [11]), the VOT durations are the inverse of what is found in Finnish.

Recall also that the amplitude of V2 was higher after geminate consonants than singleton consonants in most cases, similar to Pattani Malay [2]. As with vowel duration, however, the fact that vowel length interacts with the amplitude of V2 is unexpected and warrants further research.

In addition to the amplitude of the following vowel, the amplitude of the release burst of geminate stops was louder than that of singleton stops. Although other studies have indicated that geminate consonants are often associated with an increase in amplitude, the locus of that amplitude increase seems to vary cross-linguistically, occurring post-consonantly in Finnish, Pattani Malay, and Cypriot Greek, but pre-consonantly in Japanese. Cypriot Greek seems the most comparable with Finnish in this regard, as geminate stops had a higher RMS amplitude immediately following them than did singleton stops [11].

Based on these results, it appears that at least some of the acoustic correlates of stop length contrasts, such as the length of preceding and following vowels and the duration of VOT, are language-specific—although the prosody of the languages in question may well play a role in determining what sort of

pattern is manifested—while other correlates, such as an increase in amplitude surrounding geminate stops, might tend to be more universal, although variation is still seen in the realization of these correlates cross-linguistically. The mixed results for Finnish may come from the fact that the language has a variety of prosodic features that make it like a syllable- or stress-timed language while also having mora-like features in that robust length contrasts of both consonants and vowels are present in the language. Finnish may thus represent a typologically-intermediate language which differs in how long and short stops interact with surrounding segments.

5. References

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