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THE EFFECT OF MORA-TIMING ON THE DURATION OF VOWELS PRECEDING GEMINATE CONSONANTS

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This paper investigates the relationship among geminate consonants, preceding vowels, and timing in different types of languages. While it has generally been assumed that a predictable relationship between the geminates and preceding vowels exists only in syllable-timed languages, I show that the relationship is also (to a certain degree) predictable in mora-timed languages. However, while in syllable-timed languages vowels are shortened before geminate consonants, in mora-timed languages they are lengthened. I argue that this lengthening is due to the presence of a bimoraic foot in the mora-timed languages investigated here.

1. INTRODUCTION. The effect of consonant gemination on preceding vowels has been widely discussed in the literature, together with the general effect of closed syllables on vowels. The phenomenon of vowel shortening in closed syllables has been at the forefront of the discussions. It has been generally recognized that vowels tend to shorten in closed syllables, including syllables closed by geminate consonants (cf. Maddieson 1985, Ham 2001:135).

This paper will concentrate on languages in which vowels are lengthened before geminate consonants. I will show that while vowel shortening before geminates may be more common cross-linguistically in syllable-timed languages, vowel lengthening in the same position is not as exceptional as previously assumed in the literature. I will further show that there is a connection between the geminate-to-singleton ratio and vowel lengthening, as well as a connection between the timing of a language and the presence of vowel lengthening before geminates.

2. DISCUSSION OF PREVIOUS RESEARCH. In a paper from 1978, Fukui[1] notes that in Japanese, vowels preceding geminate consonants are longer than those preceding singleton consonants (1978:10). He also notes that, in a perception study, shortened geminates are still perceived as geminate consonants (presumably if the preceding vowel is not changed), and concludes that the duration of the consonant is probably not the sole clue for the presence of the geminate (1978:10). Fukui concludes that lengthened vowels before geminates might be a secondary cue for the following geminate consonant (1978:11).

Maddieson, discussing “Closed Syllable Vowel Shortening” (CSVS), mentions “the view that -VC- sequences are units of timing organization” (1985:216). According to Maddieson, possible counterexamples to CSVS can be found in Japanese, Kusaiean (Kosraean), and Menomini (1985:214–216). Of these, only Japanese has geminates. Maddieson (citing Dalby and Port 1982, Han 1962, and Homma 1981) states that Japanese “shows no difference in the length of the vowels preceding geminate and single consonants in word-medial position” (1985:215). He explains this deviation from CSVS with the fact that Japanese is a mora-timed language, in which “the first part of the geminate consonant derives from a

[1] I would like to thank Mie Sanders for translating the paper for me. Interpretations of the data presented in the paper, and any mistakes in these interpretations, are my own.

former CV syllable" (1985:214). Maddieson, for Japanese, "reject[s] the general assumption …that the first part of a geminate is the coda of the syllable containing the preceding vowel" (1985:214). The concept that the first part of a geminate in Japanese is a syllable by itself is also supported by Jinushi, who analyses the first part of a Japanese geminate as a sequence of a consonant and a syllabic weight unit represented as follows: C ˙, forming a syllable (1963:33). This analysis is not without merit, since, as Maddieson points out, historically "the first part of the geminate consonant in Japanese derives from a former CV syllable" (1985:214).[2]

According to Fukui (1978, see above), however, vowels in Japanese are longer when they precede geminates as compared to vowels preceding singletons. This is also supported by data from Han 1994, and Aoyama 2000, 2002. If the first part of the geminate is a syllable by itself, that would explain why the preceding vowel does not shorten. It does not, however, explain why the vowel lengthens.

Han (1994:77) notes that initial segments (consonants and vowels alike) are lengthened before geminate stops in Japanese, and, citing Fukui 1978, briefly discusses the possibility that this might be a secondary cue for the following geminate consonant. She states that "[i]f a similar phenomenon also occurs in other languages exhibiting a single/geminate contrast, then the extra duration is probably a secondary feature accompanying geminate stops" (1994:77). However, Han concludes that this view is not supported by the results of other studies, citing specifically Hankamer *et al.* 1989. She states that while vowel lengthening before geminates may be a secondary cue for Japanese, it "is not a language-universal feature" (1994:77).

Gordon *et al*. (2000) connect the duration of the preceding vowel with the geminate-to-singleton ratio in a language. They state that in most languages in which the geminate-to-singleton ratio is smaller than 2:1, "vowels are substantially shorter before geminates than before single consonants" (2000:394). According to Gordon *et al.*, "[i]n languages that display greater durational differences between geminates and singletons, vowels tend not to differ greatly as a function of whether they precede a geminate or a single consonant" (2000:394). The languages Gordon *et al.* cite as examples of greater than 2:1 geminate-to-singleton ratio with no great difference between vowel durations are Turkish (mean difference in vowel duration 3.5%), Estonian (9.1%), standard Finnish (20.3%), Japanese (1.1–8.7%), and Sinhala (19.6% for short vowels, 4.4% for long vowels) (2000:395).

While some of these differences are quite small, others seem fairly large, e.g. Finnish (20.3%). Apart from that, the numbers cited by Gordon *et al.* are questionable. For Turkish, the source cited by Gordon *et al.*, Lahiri and Hankamer 1988, actually shows that Turkish vowels are 3.5% **longer** before geminates than before singletons (1988:331). Gordon *et al.* claim the opposite. Gordon *et al.*, citing Lehtonen 1970, state that "phonemic short vowels are 20.3% shorter before geminate *p:* and *s:* than before geminate [sic] *p* and *s* (results pooled over both pairs from Lehtonen 1970)" (2000:395). I assume that the first set of sounds is meant to refer to geminates, while the second refers to singletons. Since there is no page number given for the Lehtonen source, I do not know exactly where these numbers originate, but I would like to point out that the source in question shows that for bisyllabic words, short vowels before geminates are actually on average 24% **longer** than before singletons (and long vowels are also longer before geminates than before singletons

[2] "Strict CV" approaches assume that even synchronically languages consist only of CV syllables, cf. Rowicka 1999.

(Lehtonen 1970:127–128)). As far as Japanese is concerned, I agree with Gordon *et al.* that vowels are longer before geminates than before singletons, by the percentage given by Gordon *et al.* (1.1–8.7%), cited from Han (1994).

In this paper I will investigate Gordon *et al.*'s claim (2000:394) that vowels preceding geminates vs. singletons do not differ greatly in languages with large geminate-to-singleton ratios.

Ham (2001:212) proposes that "ratios [of geminate-to-singleton consonants] are for the most part considerably larger for mora-timed languages [than for syllable-timed languages]." This proposal is essentially supported by the data presented by Ham, and by data collected for this paper. Ham (2001:240) states that in mora-timed languages, "preceding vowel duration is not phonologically or phonetically conditioned to cue the singleton-geminate contrast", and that in mora-timed languages "vowel duration raises practically no expectations about the quantity of the following consonant." Since Ham equates mora-timed languages with languages with large geminate-to-singleton ratios, his position is basically identical to that of Gordon *et al*. (2000).

In order to explain vowel shortening before geminates in syllable-timed languages, Ham (2001:169) states that "[c]losed syllable shortening … is indicative of an overall timing strategy which seeks to equalize the temporal interval between syllables (as opposed to moras)," i.e., shorter vowels before geminates are normal for a syllable-timed language, as a type of compensation. This would explain why in mora-timed languages vowels do not shorten before geminates, but again, it does **not** explain why they **lengthen**.

3. KEY ISSUES. The key issues that are discussed in this paper follow:

Are there significant differences in vowel durations before geminates vs. before singletons in languages with large geminate-to-singleton ratios and/or mora-timing? (This question addresses the claims of Gordon *et al*. 2000 and Ham 2001 that there are not.)

What type of languages (in terms of timing and/or geminate-to-singleton ratio) display the phenomenon of vowel lengthening before geminates?

Can vowel lengthening before geminates be seen as a universal phenomenon, possibly as a cue for the geminate? (This question addresses the claim by Han (1994) that this is not a universal phenomenon, and addresses Fukui's (1978) statement that at least for Japanese this is a secondary cue for the geminate.)

What is the role of timing in connection with vowel lengthening before geminate consonants?

4. METHODOLOGY. For this survey I collected data from a number of published papers and books. In order to make sure that the values I was comparing were comparable, I followed these guidelines:

I used data only from sources that explicitly stated how consonant duration was measured, and whether VOT was included under consonant duration or not. It is important to know whether VOT was included in the consonant, since including or excluding it from consonant duration will alter the resulting geminate-to-singleton ratios quite a bit.

Where possible, I calculated two separate consonant duration values from the data: closure duration only, and closure duration plus VOT. For the purpose of this paper I assume that consonant duration consists of closure duration plus VOT.

In most languages surveyed in this paper, the data were collected by embedding the target words into sentences, which were then read by the subjects. The exceptions were Chickasaw (the data were read in the form of wordlists, not embedded in sentences (Gordon *et al.* 2000:2)), and Turkish and Bengali (the words were read three times in random order, also not embedded in a sentence (Lahiri and Hankamer 1988:334)). Despite these differences I have included both types of data in this study. If I had restricted my sample to only words read in carrier sentences, I would have had too few languages to make the comparison worthwhile.

I calculated singleton and geminate duration averages from medial stops only. I did this because some sources (e.g., Han 1994) gave only data for medial stops.

I calculated vowel durations from short vowels only, since in some languages (e.g., Japanese) long vowels are not generally allowed before geminate consonants.

5. DATA. For sources of the data, please see Appendix I. The languages in table 1 are sorted by descending size of geminate-to-singleton ratio, where the duration of consonants is assumed to consist of closure and VOT. In Table 1 and Table 2, V-g means 'vowel preceding a geminate', and V-s means 'vowel preceding a singleton'.

TABLE 1. Vowel duration ratios, languages sorted by ratio CC : C (closure+VOT).

Language	ratio V-g : V-s	**ratio CC : C (closure+VOT)**	ratio CC : C (closure only)	Timing
Japanese	1.04	**2.51**	2.79	mora
Hungarian	1.04	**2.35**	1.43	mora
Levantine Arabic	1.02	**2.02**	2.25	mora
Turkish	1.04	**2.00**	2.93	mora
Finnish	*1.24*	***1.98***		*mora*
Bengali	1.26	**1.75**	1.94	mora
Chickasaw	0.86	**1.45**	1.55	?
Madurese	0.64	**1.45**	1.55	syllable
Persian	1.18		2.41	?
Swedish	0.48		1.89	syllable
Iraqi Arabic	0.83		1.99	?

In this paper, "large geminate-to-singleton ratio" is taken to mean a ratio of 2:1 or larger. (I am tentatively including Finnish as a language with a large geminate-to-singleton ratio, since two of the three measured voiceless stops (p, t) have a ratio of 2:1 or larger, while one stop (k) has a smaller ratio.)

The sample contains six mora-timed languages (Japanese, Hungarian, Levantine Arabic, Turkish, Finnish, and Bengali), and two syllable timed-languages (Madurese and Swedish). For three of the languages (Chickasaw, Persian, and Iraqi Arabic) I was not able to find information regarding their timing.[3]

Table 2 lists the languages in the sample sorted by their geminate-to-singleton ratio, taking the duration of consonants to be the closure only (excluding VOT). As stated earlier, I take consonant duration to consist of closure and VOT, but for some languages, only data for closure duration were available. By including these data, I was able to look at data from more languages.

[3] If Persian is a mora-timed language, and Chickasaw and Iraqi Arabic are syllable-timed languages, the claims made in this paper would be strengthened. If these languages use other timing strategies, the claims made in this paper would be weakened to some degree.

TABLE 2. Vowel duration ratios, languages sorted by ratio CC : C (closure only).

Language	ratio V-g : V-s	**ratio CC : C (closure only)**	ratio CC : C (closure+VOT)	Timing
Turkish	1.04	**2.93**	2.00	mora
Japanese	1.04	**2.79**	2.51	mora
Persian	1.18	**2.41**		?
Levantine Arabic	1.02	**2.25**	2.02	mora
Iraqi Arabic	0.83	**1.99**		?
Bengali	1.26	**1.94**	1.75	mora
Swedish	0.48	**1.89**		syllable
Chickasaw	0.86	**1.55**	1.45	?
Madurese	0.64	**1.55**	1.45	syllable
Hungarian	1.04	**1.43**	2.35	mora
Finnish	1.24		1.98	mora

6. DISCUSSION.

6.1 DIFFERENCE IN VOWEL DURATION BEFORE GEMINATES VS. SINGLETONS. This section addresses the question of whether there is a significant difference in the duration of vowels before geminates vs. before singletons in languages with a large geminate-to-singleton ratio and/or mora-timing, addressing the claim by Gordon *et al*. (2000) and Ham (2001) that there is not.

Referring to Table 1, the average difference in vowel duration for languages with a geminate-to-singleton ratio of 2:1 or larger (including Finnish, for reasons explained above) ranges from 2% to 24%. In each case, the vowel before the geminate is longer than the vowel before the singleton. The same is true for Table 2, where only closure duration is taken into consideration. At first glance, it seems that at least for Finnish the difference in vowel duration may be statistically significant. In fact, Lehtonen states that “[i]n the pair CVCV/CVCCV the first syllable vowel preceding the geminate consonant is 20%, and in the pair CVCVC/CVCCVC 40% longer than when preceding a single consonant,” a difference he calls “statistically strongly significant” (1970:111).

The data for Japanese were taken from Han 1994. The Japanese vowel durations were calculated only from those sets of vowels (before geminate vs. before singleton) for which none of the subjects had zero durations. Zero durations of vowels means that the vowel in question has been deleted. High vowels may be devoiced or deleted in Japanese if they occur between two voiceless sounds. Taking the words used by Han (1994) as examples, *supai* may be pronounced as [su̥pai] or [spai]. The measurement for the [o] in *yoka* vs. *yokka* is not available from Han 1994:77, since for this word the measurement for the vowel includes the preceding glide. If the ratio had been calculated from all average vowel durations, including those containing zero durations, the geminate-to-singleton ratio would have been 1.3, instead of 1.04, as shown in Tables 1 and 2. It could be argued that calculations for the ratio of vowels preceding geminates vs. vowels preceding singletons should include those instances where vowels are realized as zero before singletons. The fact that high vowels are apparently never deleted before geminates, while they can be deleted before singletons, may be due to perceptual factors. A vowel boundary before the CC makes the boundary more perceptible, because the transition between a vowel and a consonant is more salient than the transition between two consonants. This audible transition may be necessary because it makes it easier to determine the length of the following geminate.[4,5]

For Hungarian, Ham notes that for one speaker, who has longer vowels before geminates, the difference in vowel duration is statistically significant (ratio: 1.09, $F(1,34) = 8.1869$, $p = .0072$). For the other speaker, vowels are slightly shorter before geminates, but the difference is not statistically significant (ratio: 0.99, $F(1,34) = .07363$, $p = .7873$) (Ham 2001:155). It would be necessary to obtain data from more speakers before making further statements about differences in vowel duration in Hungarian.

In Levantine Arabic, vowels are also longer before geminates than before singletons, but the difference is not statistically significant, (in a one-way repeated-measures ANOVA, $F(1,2) = .750$, $p = .4778$ (cf. also Ham (2001:135), "[s]ingle-factor ANOVAs performed for each speaker show no significant main effect for syllable structure on short vowel duration").

For Turkish, Lahiri and Hankamer state that difference in duration of the preceding vowel shows "no overall significant effect" (1988:332).

As cited above, Ham (2001:212) proposes that "ratios [of geminate to singleton consonants] are for the most part considerably larger for the mora-timed languages [than for syllable-timed languages]." The data for Bengali cited here do not follow the pattern proposed by Ham for mora-timed languages (greater than 2:1 geminate-to-singleton ratio). However, Bengali does have longer vowels before geminates than before singletons. The difference in duration "is marginally significant overall ($p = 0.002$)," according to Lahiri and Hankamer (1988:335).

For Persian, vowels are longer before geminates than before singletons. A one-way, repeated-measures ANOVA run on data from all three speakers shows that the difference is statistically significant: $F(1,2) = 275.528$, $p = .0036$. The geminate-to-singleton ratio is well over 2:1.

This concludes the discussion of mora-timed languages and languages with a large geminate-to-singleton ratio. For the syllable-timed languages in the sample, vowels before geminates are shorter than vowels before singletons.

For Madurese, Ham states that the difference between the duration of [a] before geminates vs. before singletons is statistically significant, [a] being shorter before geminate consonants (2001:169). A one-way, repeated-measures ANOVA run on data from both speakers shows that the difference is statistically significant, $F(1,1) = 658.778$, $p = .0248$.

For Swedish (Hassan 2002), it could not be calculated from the data given in the source whether the difference between vowels before geminates vs. before singletons is statistically significant, since no breakdown of the data by speaker was given. However, the difference is in any case very large.

These results are expected, since according to Gordon *et al.*, in languages with smaller than 2:1 geminate-to-singleton ratios, vowels tend to be "substantially shorter before geminates than before single consonants" (2000:394). In addition, languages with smaller than 2:1 geminate-to-singleton ratios tend to be syllable-timed, according to Ham (2001:212).

[4] Victoria Anderson, personal communication, October 2004.

[5] An alternate explanation is that while consonant clusters containing two singleton consonants are allowed in Japanese on a phonetic level, consonant clusters containing even one geminate consonant are not allowed in the onset. In fact, I am not aware of any language that does allow such clusters in the onset. I owe Ken Rehg for pointing out possible phonotactic constraints in connection with this.

For the following languages, no information about the timing could be found, but the geminate-to-singleton ratios are substantially smaller than 2:1.

For Chickasaw, Gordon *et al*. report that vowels are significantly longer before singleton than before geminates for [p] vs [p:] (paired t-test, $t(1,25) = 4.618$, $p = 0.0001$), but not for [t] vs. [t:] (2000:397).

For Iraqi Arabic, the geminate-to-singleton ratio is just barely under 2:1, but vowels are clearly shorter before geminates than before singletons. No information regarding statistical significance is available.

Both Chickasaw and Iraqi Arabic follow the pattern proposed by Gordon *et al*. (2000:394), that vowels tend to be "substantially shorter before geminates than before single consonants" in languages with smaller than 2:1 geminate-to-singleton ratios.

According to Ham (2001:212), mora-timing implies a large geminate-to-singleton ratio. Of the six languages in Table 1 with mora-timing (Japanese, Hungarian, Levantine Arabic, Turkish, Finnish, and Bengali), all but Bengali have greater than 2:1 geminate-to-singleton ratios. Of the mora-timed languages, two languages have a statistically significant difference in vowel duration (Finnish and Bengali), and one language has a significant difference for one of two speakers (Hungarian). Statistical significance cannot be determined for Japanese (since Han did not provide a breakdown of the data by speaker), but the difference in vowel duration is in any case substantial. Two of these languages do not have a significant difference in vowel durations (Levantine Arabic and Turkish). Persian has a greater than 2:1 geminate-to-singleton ratio (and probably is mora-timed; see below), and also has a significant difference in the duration of vowels before geminates vs. before singletons. Given these results, the claim that there is no great difference in vowels preceding geminates vs. singletons in languages with large geminate-to-singleton ratios (Gordon *et al*. 2000:394) must be amended.

6.2 WHAT TYPES OF LANGUAGES HAVE LONGER VOWELS BEFORE GEMINATES VS. SINGLETONS? The previous section has addressed differences in vowel durations before geminates vs. before singletons. This section addresses the direction of vowel duration differences, and, more specifically, the question: What types of languages, in terms of timing and geminate-to-singleton ratio, display the phenomenon of vowel lengthening before geminates?

As can be seen in Table 1 above, there are a number of languages that have longer vowels before geminates than before singletons. In fact, all of the languages with geminate-to-singleton ratios (closure+VOT) of 2:1 or larger have longer vowels before geminates (including Finnish, for reasons explained above). The only language in the sample with a smaller than 2:1 geminate-to-singleton ratio, but longer vowels before geminates, is Bengali. The same pattern holds for Table 2.

In terms of timing, all languages in Table 1 (and Table 2) with mora-timing have longer vowels before geminates than before singletons. Of the six mora-timed languages in the sample (Japanese, Hungarian, Levantine Arabic, Turkish, Finnish, and Bengali), two have statistically different vowel durations before geminates vs. before singletons (Finnish and Bengali), and one has a statistical difference in vowel duration for only one speaker (Hungarian). Japanese has a large difference in vowel duration, but it cannot be determined whether the difference is statistically significant. Two languages (Levantine Arabic and Turkish) do not have a statistically significant difference in the duration of vowels before geminates vs. before singletons. There are no syllable-timed languages with longer vowels before geminates.

In this study, data for Bengali are taken from Lahiri and Hankamer 1988. However, data for Bengali from Hankamer *et al.* 1989 show almost the opposite trend from that shown in Lahiri and Hankamer 1988. In Hankamer *et al.* 1989, the geminate-to-singleton ratio (closure + VOT) is 2.29, while the ratio of V-g to V-s is 0.96 (calculated from data given in Table 1, p. 288). If the numbers from Hankamer *et al.* 1989 are correct, Bengali is the only language in the sample with mora-timing and a greater than 2:1 geminate-to-singleton ratio that has a smaller than 1 ratio of vowels preceding geminates vs. those preceding singletons.[6]

Assuming that the conclusions above are correct, i.e., that vowels are longer before geminates than before singletons in mora-timed languages, we can conclude that Persian may be mora-timed, since vowels are significantly longer before geminates than before singletons. In addition, the geminate-to-singleton ratio is well over 2:1.

Following the same reasoning, Chickasaw and Iraqi Arabic should be syllable-timed languages, since in these languages vowels are shorter before geminates than before singletons. In addition, these languages have geminate-to-singleton ratios much smaller than 2:1.

To summarize, none of the languages in the sample which are generally considered to be mora-timed undergoes vowel shortening before geminates. Since mora-timed languages tend to have greater than 2:1 geminate-to-singleton ratios (Ham 2001:212), this means that languages with greater than 2:1 geminate-to-singleton ratios have longer vowels before geminates.

7. WHY ARE VOWELS LONGER BEFORE GEMINATES THAN BEFORE SINGLETONS IN SOME LANGUAGES? The fact that in certain languages vowels are lengthened before geminates needs to be explained. Existing explanations make it clear why vowels do not shorten before geminates in mora-timed languages, but they do not explain why they lengthen. In mora-timed languages, there is no need to keep syllables isochronous; therefore, vowels do not shorten before geminates. This has led linguists to assume that there is nothing predictable about vowels before geminates in mora-timed languages (cf. Ham 2001). However, according to the data presented here, there is a pattern that needs to be explained. The observed pattern may be due to either one of two factors, of a combination of both: in mora-timed languages, lengthened vowels serve as a cue for following geminate consonants, and/or lengthened vowels before geminates are due to the overall timing strategy of the language.[7]

7.1 LENGTHENED VOWELS AS A CUE FOR GEMINATES. Can vowel lengthening before geminates in mora-timed languages be seen as a universal phenomenon, possibly as a cue for the following geminate? This section addresses the claim by Han (1994) that this is not a universal phenomenon, and addresses Fukui's (1978) statement that at least for Japanese this is a secondary cue for the geminate.

It would be necessary to conduct perception studies to be able to address this question properly. However, it is possible to make some preliminary observations.

[6] The numbers from Hankamer *et al.* 1989 regarding Turkish also differ from those given in Lahiri and Hankamer 1988, but the overall pattern is preserved, if only marginally.

[7] Another approach might be the one presented by Rowicka (1999:73f) in her analysis of long and short vowel alternations, where the short vowel appears in an open syllable, and the long counterpart in the closed syllable. Rowicka (1999:74) argues that the long vowels are the "result of lengthening of an originally short vowel under certain prosodic conditions", i.e., deletion of a final vowel.

According to Fukui (1978:11), while Japanese vowels are longer before geminates than before singletons, these lengthened vowels are never perceived as phonemically long vowels (although Japanese does have phonemically long vowels). Fukui proposes that lengthened vowels cue the following geminate consonant (1978:11). According to his research, listeners classified singleton-length consonants as geminate consonants if they were preceded by a lengthened vowel (1978:11).

According to Ham (2001:240), in mora-timed languages "preceding vowel duration is not phonologically or phonetically conditioned to cue the singleton-geminate contrast," and "vowel duration raises practically no expectations about the quantity of the following consonant." However, it seems that in the data at hand, a longer than "normal" vowel in mora-timed languages is always followed by a geminate consonant. In my opinion, at least for those languages in which the difference in vowel durations is statistically significant, it can be stated that the longer vowel is a cue for a following geminate in mora-timed languages. If this is the case, then both syllable-timed languages and mora-timed languages use preceding vowel duration as a cue for the following consonant: in syllable-timed languages, a shorter vowel signals a geminate, while in mora-timed languages a longer vowel signals a geminate.

7.2 VOWEL LENGTHENING BEFORE GEMINATES DUE TO MORA-TIMING. Ham (2001:169) states that "[c]losed syllable shortening … is indicative of an overall timing strategy which seeks to equalize the temporal interval between syllables (as opposed to moras)," i.e., shorter vowels before geminates are normal for a syllable-timed language, as a type of compensation. Mora-timed languages do not need to equalize intervals between syllables, so there is no need to shorten vowels before geminates. But why is the vowel lengthened?

If the aim is to create morae of equal length, we would expect compensatory phenomena within morae. For example, we would expect vowels to be longer after intrinsically short onset consonants within the same mora, and shorter after intrinsically long onset consonants within the same mora (cf. Beckman (1982:124)). However, according to Beckman, there is no consistent evidence that such compensation takes place. What looks like compensation in some cases is, according to Beckman, more convincingly explained by other factors, such as oral pressure, affrication, and measurement errors (127-131). Beckman's research also found no evidence supporting the claim that a consonant preceding a deleted vowel compensates for the length of that vowel (1982:118).

However, compensation may be a phenomenon affecting a unit longer than just one mora. Concerning compensatory strategies across morae, discussions can be found in Beckman 1982, Port *et al*. 1987, Ham 2001, Warner and Arai 2001, and Ota *et al*. 2003, among others.

Beckman, researching the phonetic reality of the mora for Japanese, compared the duration of CCV sequences (two morae) to those of CV sequences (one mora) where CC is a long consonant, and found that the ratio was 1.66:1 (1982:123). (While this is not explicitly stated, the sequences compared were most likely sequences following a vowel, since Japanese does not allow words beginning with a long consonant). She argues that this is evidence against the hypothesis that morae have equal duration, since the expected ratio would be 2:1 (1982:123). Beckman also investigates compensation across mora boundaries, specifically the claim that "a vowel's duration [varies] inversely with the durations of a following syllable-initial consonant" (1982:131). Beckman sees a number of problems with compensation across mora boundaries:

1. This type of evidence "cannot be evidence for the mora as it is usually defined" (1982:132).
2. "[T]he nearly constant duration of two-mora words in both experiments is probably due in large part to the homogeneity of the two-mora words tested" (1982:132). The words tested in the experiments cited by Beckman all had the shape CVCV, in addition to other structural similarities.
3. [I]t is possible that vowels were shorter before voiceless stops than before voiced ones because of universal tendencies (1982:132).

The experiments investigated by Beckman were those by Homma (1981) and Port *et al.* (1980), both for Japanese. Beckman's conclusion is that there is "no convincing evidence for the phonetic reality of the mora" (1982:133).

Ham states that to his knowledge "the perceptual relevance of isochrony in mora-timed languages" "has not been addressed" (2001:243). However, he does not think that mora timing creates isochrony of morae (2001:244):

> Since mora-timed languages by definition tend to regularize the temporal spacing between units smaller than the foot or (often) the syllable, any systematic tendency to perceptually regularize the distance between these larger units would seem to be at cross-purposes with the maintenance of context-independent quantity contrasts in consonants and vowels. In Hungarian, for example, it is difficult to see how a perceptual equalization of the temporal distance between syllables – as for example in Italian or Madurese – would allow the four-way contrast among VC, V:C, VC: (or VCC), and V:C: (or V:CC) sequences to be preserved.

I disagree with the statement that "mora-timed languages by definition tend to regularize the temporal spacing between units smaller than the foot"; i.e. morae. In my opinion, there is evidence that in mora-timed languages words containing an equal number of morae are approximately of equal length, but not because of isochronous morae.

If compensatory strategies for morae take place across words, we would expect words of the same number of feet to have approximately similar lengths. Beckman cites Homma 1981 as measuring a ratio between CVCCV and CVCV words of 3:2 (1982:122), but states that the "3:2 ratio is skewed," since Homma includes long voiced stops as well (1982:123). The ratio of long vs. short voiced stops is much greater than that of long and short voiceless stops, and long voiced stops are only peripherally a part of the Japanese phoneme system (Beckman 1982:123). According to Vance (1987:42), long voiced obstruents occur only in recent loanwords (such as *baggu* for 'bag'), and usually have voiceless alternates (*bakku*). Since long voiced stops are a relatively new phenomenon, and may not be in the inventory of every native, monolingual speaker of Japanese, they should be excluded from a study looking at the underlying timing of Japanese long consonants.

While Homma's ratio may be skewed, a cursory survey of the literature seems to support the assumption that words containing the same number of morae have approximately equal duration. For Japanese, Han (1994:76) shows the following numbers (averaged over the means of ten subjects):

kitte	397.6 ms
supori	377.9 ms

Finnish data from Lehtonen (1970:117 and 122) show the following mean durations of three-mora words:

CVCCV	360 ms
CVCVCV	377 ms

In both cases, the durations for the two-syllable word seem to be very similar to those of the three-syllable word.

If not because of isochronous morae, why do words with an equal number of morae have equal durations in mora-timed languages? I would like to propose that instead of keeping morae isochronous, mora-timed languages create isochronous feet, normally consisting of two morae.

Warner and Arai (2001a) review and summarize research regarding Japanese mora-timing. Among other hypothesis, they review research dealing with higher-level mora timing, e.g., the hypothesis that the domain of compensation is not the mora, but the word or foot (2001a:8–10). Warner and Arai, with reference to Han 1994, state in relation to longer segments before geminates than before singletons that "if geminate obstruents are too short to contribute a full mora's duration, this is the expected result under the high-level mora-timing hypothesis: a geminate makes the word somewhat short, so surrounding segments, such as the preceding one, are lengthened" (2001a:10). (Han 1994 refers to initial segments of a word, which may or may not be adjacent to the geminate or singleton.) However, Warner and Arai (2001:10) also review evidence contradicting higher-level mora timing, such as the shortening of final segments in words containing geminates, shown in Han 1994. According to Warner and Arai (2001a:10), Warner and Arai (2001b) "conclude that Japanese does not use the mora as a unit of high level durational compensation."

Port *et al.* (1987:1578) find "that word durations are highly dependent on the numbers of moras in a word". They note that "for two-syllable words, the domain of temporal compensation for segment duration effects is larger than the CV syllable" (1987:1581).

Ota *et al.* (2003) mention the bimoraic foot as the domain of compensation in Japanese. Comparing words consisting of CV morae only, Ota *et al*. concluded that "[i]t is possible that the role of the foot is to provide a domain of this [inter-mora] compensation such that the trade-off takes place mostly, if not exclusively, between moras that share a foot" (2003:462). Following Hayes (1995), Inaba (1006:9) identifies the foot structure of Japanese as moraic trochees. Inaba (1996:9) states for Japanese that there exists "an isochronous unit called a foot"[8]. Inaba (1996:49) states that "[i]t is assumed that moras or bimoraic feet are isochronous units in Japanese".

According to Poser (1990), in Japanese a bimoraic foot plays a role in such phenomena as hypocoristic formations, kinship terms, geisha/bargirl client names, rustic girls' names, *renyookei* reduplication, mimetics, secret language, and the accentuation of noun-noun compounds.

I propose that not just Japanese, but mora-timed languages in general[9] use the bimoraic foot as a domain of compensation between morae.

The following figures are schematic representations of two three-mora words, one with three syllables (CVCVCV), and one with two syllables and a geminate consonant (CVCCV)

[8] However, it is not clear from Inaba (1996:41-42) whether he perceived temporal compensation as taking place between mora or between feet.

[9] this holds at least for languages with moraic trochees. Whether it also holds for languages with iambic systems needs to be investigated.

As shown above, both words, having the same number of morae, should have similar duration. Individual morae do not have to be isochronous.

While words containing an even number of morae can conceivable be parsed exhaustively into bimoraic feet, words containing an uneven number of morae need to deal with any 'left-over' morae in some way. How the 'left-over' mora is treated in any one case will depend on the language and possibly also the position of the mora in the word. For Japanese, Inaba (1996:108, 117, cf. also 58) proposes that medial and final stray morae are attached to the preceding foot, creating surface ternary feet. Citing Teranishi (1980), Inaba (1996:44) also states that in Japanese in slow speech final stray morae lengthen "to meet the bimoraic requirement" [of a foot], creating a degenerate foot. However, according to Inaba (1996:76), "[d]egenerate feet are only allowed at the right peripheral edge".

I propose that in mora-timed languages in general, in order to create words of equal duration, the duration of the feet is kept equal. There are two possibilities by which, under these conditions, words containing the same number of morae can be kept isochronous. Figures 1 and 2 illustrate these possibilities for tri-moraic words, assuming that the final mora forms a foot of its own.

Assuming that there is really no significant change in the duration of the vowel preceding the geminate consonant, the long consonant has to be long enough to have the duration of two consonants and one vowel, as illustrated in Figure 1. That would explain why geminates have such long durations in mora-timed languages.

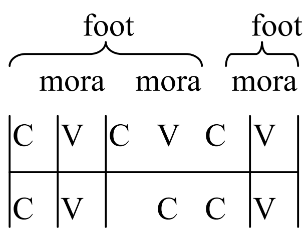


FIGURE 1

If the preceding vowel were to also become longer, then the duration of the geminate consonant would not have to be quite as long to preserve the same duration for the whole word. Instead, the preceding vowel and the geminate consonant together would ensure a three-mora duration for the whole word. Unless the vowel is exceptionally long, the geminate consonant would still have to be longer than in a syllable-timed language in order to preserve a duration of three morae (see Figure 2).

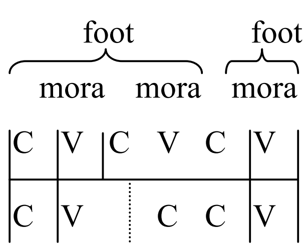


FIGURE 2

According to Ham (see quote above), creating isochronous units in mora-timed languages would "be at cross-purposes with the maintenance of context-independent quantity contrast in consonants and vowel," i.e., if mora duration can be adjusted to create isochronous feet, the phonemic distinction between vowels would be endangered. How would the listener know whether a vowel was a lengthened short vowel, or a phonemically long vowel? With isochronous feet this should not be a problem. In Japanese, long vowels only very rarely appear before geminate consonants (cf. Vance 1987:72). In Hungarian, long vowels can appear before geminate consonants. However, for the speaker who has lengthened vowels before geminates (119 ms), the long vowel before a geminate is 177 ms long, making it clearly distinct from the short vowel (Ham 2001:155). Finnish also allows long vowels to appear before geminate consonants. Here, short vowels before geminates are 80 ms, vs. 130 ms for phonemically long vowels before geminates (Lehtonen 1970:127–128). This means that although these two languages lengthen short vowels before geminates, these lengthened vowels are still clearly distinguishable from phonemically long vowels in the same position. Isochrony between single morae may not be possible, but isochrony as described above is possible in mora-timed languages. Inaba states that "it is possible to find a tendency toward foot isochrony by comparative methods" (1996:96). Inaba (1996:108) finds that in words consisting of a bimoraic foot followed by a stray mora and another bimoraic foot, the first foot is shorter than the first, suggesting "that the word-medial stray mora…attaches to the preceding shortened foot". He also states that for Japanese, "feet that may be bimoraic or trimoraic…are the basic timing units" (1996:174).

If we assume a (bimoraic) foot as the domain for isochrony in Japanese (and other mora-timed languages), we can explain why one mora (the mora containing the preceding vowel) would lengthen to compensate for the length of a following mora (the mora containing the first half of the geminate consonant). We have to assume that feet are constructed left to right. At the moment, there is no definite consensus regarding the directionality of foot construction in Japanese. According to Poser (1990:101-2), there is evidence for foot construction from left to right, as well as from right to left.

In support of foot construction from left to right, Poser (1990:102) cites Teranishi 1980. Teranishi investigated the reading of verse in Japanese, noting that in slow-speed reading, two moras behave as a cluster (1980:S40).

Inaba proposes that in Japanese, morae are initially parsed into feet from right to left (1996:63), with subsequent parsing of morae into bimoraic feet from left to right (1996:74).

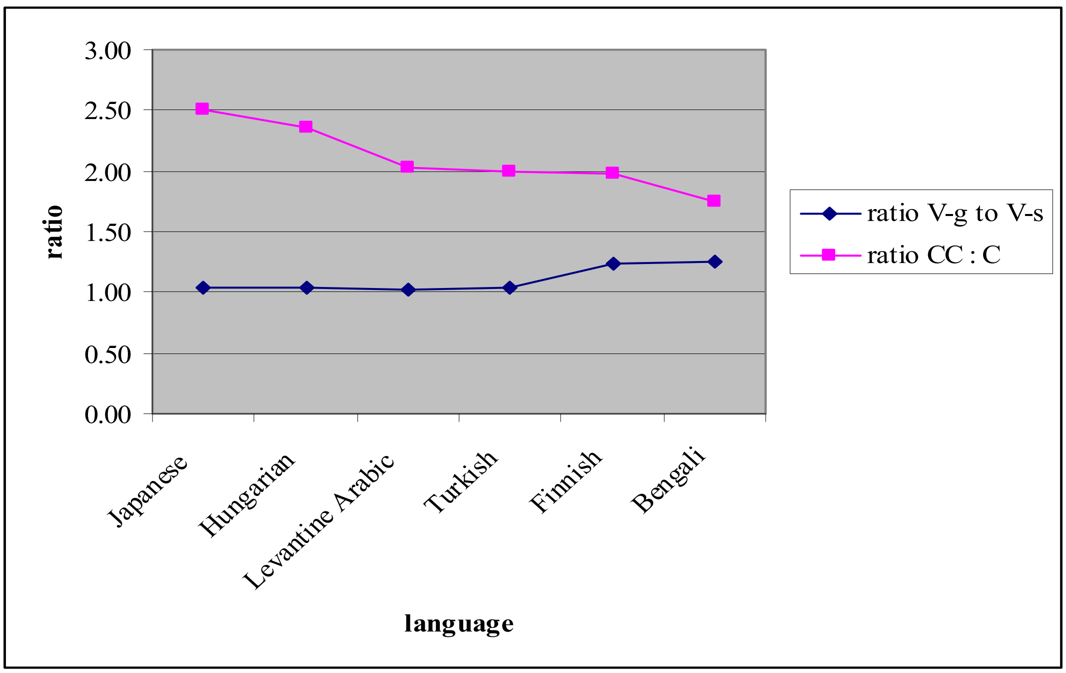
I propose that all mora-timed languages discussed in this paper create isochrony across a bimoraic foot that is constructed from left to right. Based on the data presented here, I predict that languages which construct bimoraic feet from left to right, and in which geminates are moraic, vowels are lengthened before geminates in order to create feet of roughly equal duration. According to Tranel (1991), in some languages codas, including those formed by the first half of a geminate, do not contribute to the weight of the syllable. In those languages I would not expect the vowel to lengthen before a geminate. As examples of languages in which the coda of a syllable (whether or not it is part of a geminate) does not contribute a mora, Tranel (1991: 294) cites Selkup, Mayalayam, and (as a possible candidate)

Tübatulabal. Also, in languages in which feet are not constructed from left to right on any level, vowel-lengthening before geminate consonants would not be expected.[10]

Assuming that mora-timed languages have isochronous feet, where the foot is constructed from left to right, would also explain Beckman's 1.66:1 ratio for CCV vs. CV sequences (1982:123). We would expect a 2:1 ratio for these sequences only if feet were constructed from right to left.

Assuming that vowel lengthening before geminates takes place in order to produce bimoraic feet of equal length also explains another pattern found in the data: mora-timed languages with smaller geminate-to-singleton ratios tend to have longer vowels before geminates. If a certain duration needs to be maintained for a bimoraic foot, then the shorter a geminate consonant is, the more of the duration needs to be made up by the preceding vowel. However, this argument needs to be confirmed by clearer data. The geminate durations here are calculated from stops only. However, in Finnish, for example, the overall geminate-to-singleton ratio is quite a bit larger than the 1.98 cited here, which makes it more difficult to explain why the difference in vowel duration is so large.

TABLE 3. Degree of vowel lengthening compared to geminate-to-singleton ratio in mora-timed languages.



Warner and Arai (2001:21) argue that negative correlations "between adjacent segments … can never be good evidence for temporal compensation, because these negative correlations will also appear automatically if there is any measurement error in placing boundaries." However, it seems to be more than an error in placing boundaries if all mora-timed languages in this sample show negative correlations between geminate consonants and the preceding vowel.

[10] However, Inaba suggest "that SFP [Surface Foot Parsing] always takes place from the beginning to the end of strings" (1996:121, cf. also 20).

7.3 A COMBINED APPROACH. As discussed in sections 7.1 and 7.2, I propose that lengthened vowels before geminates may serve to cue following geminates in mora-timed languages, and that vowels lengthen before geminates in mora-timed languages[11] to create isochronous feet. Both those proposals may in fact be true for mora-timed languages. It is possible that mora-timing causes vowels to lengthen before geminates, and that speakers of mora-timed languages take advantage of this fact, using lengthened vowels as a cue for the length of the following geminate.[12]

The role that stress (or pitch accent) plays in lengthening segments has not been investigated in this paper. It is likely that vowels before geminates in mora-timed languages which carry stress or accent are longer than vowels before geminates which do not carry stress or accent. It is left to future research to investigate what role stress plays in connection with vowel lengthening before geminate consonants.

8. CONCLUSION. This paper has discussed the duration of vowels before geminate and singleton consonants in mora-timed languages. If the data surveyed in this paper are representative, vowels never shorten before geminate consonants in mora-timed languages. In fact, vowels lengthen in these positions. While the amount of lengthening is not statistically significant in all languages, vowel lengthening in these environments still merits further investigation.

I have proposed that lengthening of a vowel before geminates is due to mora-timing. In order to keep two-mora feet isochronous, vowels are lengthened preceding geminate consonants[13]. This proposal is supported by other evidence pointing to a two-mora foot in Japanese (Poser 1990, Inaba 1996, Ota *et al*. 2003). My proposal requires that the foot be constructed from left to right, as supported by Teranishi's (1980) research and by Inaba 1996 for Japanese.

9. DIRECTION OF FUTURE RESEARCH. This study raises questions about phonemic length distinctions in vowels in languages with phonetic vowel lengthening before geminates. Do phonemically long vowels have to be much longer in such languages, to avoid confusion with phonetically lengthened vowels? What about those mora-timed languages that allow long vowels before geminate consonants? How is the distinction between long vowels and lengthened vowels maintained before geminate consonants? These questions address Ham's statement that mora-timing conflicts with the presence of long vowels before geminates in some languages (2001:224).

In general, more evidence (especially from mora-timed languages) should be investigated to study the validity of the claims made in this paper. One language that might be studied with respect to the behavior of geminate consonants and vowels preceding geminates versus singletons is Pohnpeian, a language with mora-timing and phonemically long vowels and consonants.

It would also be interesting to look at the historical development of length distinctions in consonants across languages. In other words, how do geminate duration and the historical origin of the geminate relate? Lahiri and Hankamer (1988:336) state that there is no evidence that within a language (in their case, Bengali) the duration of geminates differs depending on their origin. I would not expect geminates to differ in their duration within one

[11] mora-timed languages in which the foot is constructed from left to right.

[12] I would like to thank Victoria Anderson for pointing this out to me.

[13] as states above, this holds at least for languages with moraic trochees

language depending on their origin, as long as all geminates within the language are treated the same with regard to weight. It remains to be investigated whether the historical origin of geminates can have an influence on geminate duration across languages. In addition, comparing the origin of geminates in different languages with the timing of those languages may tell us more about geminate-to-singleton ratios and the behavior of vowels before geminates.

Abbreviations

C singleton consonant
CC geminate consonant
C: geminate consonant
V-s vowel preceding singleton consonant
V-g vowel preceding geminate consonant

Appendix

Sources of durational data.

Language	**Type of Data**	**Source**	**Page, Figure/Table**
Bengali	duration of closure, VOT, and preceding vowel for Bengali singleton and geminate consonants	Lahiri and Hankamer 1988	p. 335, Figure 6
Chickasaw	singleton and geminate stop closure durations, calculated from data given here	Gordon *et al*. 2002	p. 390-393, Table 12.
Chickasaw	singleton and geminate stop VOT, calculated from data given here	Gordon *et al*. 2002	p. 387, Table 10
Chickasaw	vowels before singletons and geminates, calculated from data given here	Gordon *et al*. 2002	p. 397, Table 13
Finnish	singleton and geminate stop duration, calculated from data given here	Lehtonen 1970	p. 97, Table 10
Finnish	short vowels preceding singletons and geminates in bisyllabic words, calculated from data given here	Lehtonen 1970	pp. 116-122
Hungarian	closure duration of medial singletons and geminates, calculated from data given here	Ham 2001	p. 148, Figure 5.17 and Figure 5.18

Language	Type of Data	Source	Page, Figure/Table
Hungarian	VOT of medial voiceless singletons and stops, calculated from data given here	Ham 2001	p. 153, Figure 5.21
Hungarian	durations of short vowels before singletons and geminates, calculated from data given here	Ham 2001	p. 155, Figure 5.23
Iraqi Arabic	closure duration of singletons and geminates	Hassan 2002	p. 83, Table 4
Iraqi Arabic	duration of vowels preceding singletons and geminates	Hassan 2002	p. 83, Table 2
Japanese	duration of geminates, singletons, and respective VOTs calculated from data given here	Han 1994	p. 76–77, Table I
Japanese	duration of vowels preceding geminates and singletons, taking into account only words without zero durations of the vowel in question, calculated from data given here	Han 1994	p. 76–77, Table I
Levantine Arabic	medial singleton and geminate stop duration, calculated from data given here	Ham 2001	p. 129, Figure 5.5 and Figure 5.6
Levantine Arabic	VOT for medial voiceless singleton and geminate stops, calculated from data given here	Ham 2001	p. 133, Figure 5.6
Levantine Arabic	preceding vowels in disyllabic words, calculated from data given here	Ham 2001	p. 136, Figure 5.10
Madurese	closure durations for singleton medial stops, calculated from data given here	Ham 2001	p. 162, Figure 5.26
Madurese	closure durations for geminate medial stops, calculated from data given here	Ham 2001	p. 162, Figure 5.27
Madurese	VOT for medial singleton and geminate stops, calculated from data given here	Ham 2001	p. 167, Figure 5.31
Madurese	duration of [a] before singletons and geminates, calculated from data given here	Ham 2001	p. 168, Figure 5.32

Language	**Type of Data**	**Source**	**Page, Figure/Table**
Persian	closure durations for singletons and geminates	Hansen 2004	p. 89, Table 1, pooled, normal
Persian	durations for vowels preceding singletons and vowels, calculated from data given here	Hansen 2004	p. 89, Table 1, pooled, normal
Swedish	closure duration of singletons and geminates	Hassan 2002	p. 84, Table 8
Swedish	duration of vowels preceding singletons and geminates	Hassan 2002	p. 83, Table 6
Turkish	duration of closure, VOT and preceding vowel for Turkish singleton and geminate consonants	Lahiri and Hankamer 1988	p. 331, Figure 3

Sources for information about language timing:

Language	Timing	Source
Turkish	**mora**	Ham 2001:213,
Japanese	**mora**	Ham 2001:213 Warner and Arai 20001: 1144, Han 1994:73
Persian	**?**	
Levantine Arabic	**mora**	Ham 2001:213
Iraqi Arabic	?	
Bengali	mora	Ham 2001:213
Swedish	syllable	Ham 2001:213
Finnish	mora	Ham 2001:213
Chickasaw	?	
Madurese	syllable	Ham 2001:213
Hungarian	mora	Ham 2001:213

References:

Aoyama, Katsura. 2000. A psycholinguistic perspective on Finnish and Japanese prosody: Perception, production and child acquisition of consonantal quantity distinctions. University of Hawaiʻi at Mānoa Ph. D. dissertation.

Aoyama, Katsura. 2002. Quantity contrasts in Japanese and Finnish: Differences in adult production and acquisition. *Studies in language sciences (2)*: Papers from the Second

Annual Conference of the Japanese Society for Language Sciences, ed. by Yasuhiro Shirai, Harumi Kobayashi, Susanne Miyata, Keiko Nakamura, Tamiko Ogura, and Hidetosi Sirai, 121–135. Tokyo: Kuroshio. Available at: http://webpages.acs.ttu.edu/kaoyama/aoyama11.pdf.

Beckman, Mary. 1982. Segment duration and the ‘mora’ in Japanese. *Phonetica* 39:113–135.

Dalby, J., and Port, R. F. 1982. Temporal structure of Japanese: Segment, mora and word. *Research in Phonetics* (Department of Linguistics, Indiana University, Bloomington), 2:149–172.

Fukui, Seiji. 1978. Perception for the Japanese stop consonants with reduced and extended durations. *The Bulletin of the Phonetic Society of Japan* 159:9–12.

Gordon, Matthew; Pamela Munro; and Peter Ladefoged. 2000. Some phonetic structures of Chickasaw. *Anthropological Linguistics* 42:366–400.

Ham, William H. 2001. *Phonetic and phonological aspects of geminate timing*. New York and London: Routledge.

Han, Mieko. 1994. Acoustic manifestations of mora timing in Japanese. *Journal of the Acoustical Society of America* 96:73–82.

Hankamer, Jorge; Aditi Lahiri; and Jacuqes Koreman. 1989. Perception of consonant length: Voiceless stops in Turkish and Bengali. *Journal of Phonetics* 17:283–298.

Hansen, Benjamin B. 2004. Production of Persian geminate stops: Effects of varying speaking rate. *Proceedings of the 2003 Texas Linguistics Society Conference*, ed. by Augustine Agwuele et al., 86–95. Somerville, MA: Cascadilla Proceedings Project. www.lingref.com, document #1070.

Hassan, Zeki M. 2002. Gemination in Swedish & Arabic with a particular reference to the preceding vowel duration. An instrumental and comparative approach. *Speech, Music and Hearing, Quarterly Progress Report – Fonetik 2002*, 44:81–84. Available at: http://www.speech.kth.se/qpsr/tmh/2002/02-44-081-084.pdf

Hayes, Bruce. 1995. Metrical stress theory: Principles and case studies. Chicago: The University of Chicago Press.

Homma, Y. 1981. Durational relationship between Japanese stops and vowels. *Journal of Phonetics* 9:273–281.

Inaba, Seiichiro. 1996. Initial binary feet and surface ternary feet in metrical theory: An integrated computational analysis of loanwords and nominal compounds in Japanese. University of Hawai‘i at Ma noa Ph. D. dissertation.

Jinushi, Toshiko Susuki. 1963. The structure of Japanese: A study based on a restatement of phonology and an analysis of inflected words. State University of New York at Buffalo Ph.D. dissertation.

Lahiri, Aditi, and Jorge Hankamer. 1988. The timing of geminate consonants. *Journal of Phonetics* 16:327–338.

Lehtonen, Jaakko. 1970. *Aspects of quantity in Standard Finnish*. Jyväskylä: K.J. Gummerus Osakeyhtiön Kirjapaino.

Maddieson, Ian. 1985. Phonetic cues to syllabification. *Phonetic linguistics. Essays in honor of Peter Ladefoged.* Ed. by Fromkin, Victoria A., 203–223 Orlando: Academic Press, Inc. (Harcourt Brace Jovanovich, Publishers).

OTA, MITSUHIKO; ROBERT D. LADD; and MADOKA TSUCHIYA. 2003. Effects of foot structure on mora duration in Japanese? *Proceedings International Congress of Phonetic Sciences (ICPhS 2003)*:459–462.

PORT, R.F., S. ALI-ANI AND S. MAEDA. 1980. Temporal compensation and universal phonetics. *Phonetica* 37:235–252.

PORT, ROBERT F.; JONATHAN DALBY; and MICHAEL O'DELL. 1987. Evidence for mora-timing in Japanese. *Journal of the Acoustical Society of America* 81 (5): 1574–1585.

POSER, WILLIAM J. 1990. Evidence for foot structure in Japanese. *Language* 66:78–105.

ROWICKA, GRAZYNA. 1999. *On ghost vowels: A strict CV approach.* The Hague: Holland Academic Graphics.

TERANISHI, R. 1980. Two-moras-cluster as a rhythm unit in spoken Japanese sentence or verse. *Journal of the Acoustical Society of America*, *Supplement 1*, 67:40.

TRANEL, BERNARD. 1991. CVC light syllables, geminates and Moraic Theory. *Phonology*, 8:291–302.

VANCE, TIMOTHY J. 1987. An introduction to Japanese phonology. Albany, NY: State University of New York Press.

WARNER, NATASHA, and TAKAYUKI ARAI. 2001a. Japanese mora-timing: A review. *Phonetica* 58:1–25.

WARNER, NATASHA, and TAKAYUKI ARAI. 2001b. The role of the mora in word-level timing in spontaneous Japanese speech. *Journal of the Acoustical Society of America* 109 (3): 1144–1156.