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Acoustic characteristics of the obstruent and nasal geminates in the Ikema dialect of Miyako Ryukyuan

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Introduction

Geminate consonants are long consonants often transcribed with two consonant symbols inducing length contrasts with a singleton consonant. Among morphologically different types of geminate consonants, the underlying geminates are claimed to be moraic (Hayes, 1989; Topintzi, 2010, among others). In terms of syllable weight, a single vowel counts as one mora and a geminate consonant counts also as one mora. More precisely, it is the first half of a geminate that counts as a mora and the other half is weightless. Thus, a geminate consonant closing a syllable forms a heavy syllable having two moras. For example, a Japanese word /kaba/ ‘hippopotamus’ is a two-mora and two-syllable word, while the word /kappa/ ‘imaginary creature’ forms a three-mora and two-syllable word. The syllable boundary crosses the geminate consonant as indicated by a dot in /kap.pa/. Our study involves geminate consonants occurring not only in word-medial position but also in word-initial position.

The Ikema dialect, spoken in Miyako Island in southern Ryukyu, Japan was designated by UNESCO along with other Miyako dialects as endangered. Ikema differs from Tokyo Japanese in that it has typologically rare voiced geminate consonants as well as word-initial obstruent and nasal geminates. We investigate the acoustic characteristics of geminates in Ikema Ryukyuan by using oscillograms and spectrograms.

We first present a description of aspects of the phonological system of the Ikema dialect. The consonant inventory of the Ikema dialect is /p b t d k g ts s z f v h m n r j w N ɲ/ (adapted from Pellard & Hayashi, 2012). These phonemic symbols roughly reflect phonetic values in IPA unless mentioned otherwise. /N/ is a placeless moraic nasal. When it is used as a part of a geminate nasal stop, it assimilates to the place of the following stop consonant. When it occurs before the other elements including a pause, it realizes as a nasal glide, hence, without a release of any constriction. /ɲ/ realizes as a voiceless nasal fricative that assimilates its place to the following nasal stop: /ɲnu/ [ɲnu] ‘horn’, /ɲmu/ [ɲmu] ‘cloud’. For both /N/ and /ɲ/, when it occurs as a part of geminates, we simply transcribe them with nasal consonant symbols, for instance, as /mm/ or /ɲn/, thus conforming to the other geminate consonants such as /tt/. /r/ is typically an alveolar tap but many variants also exist. [ts] and [tɕ] are in complementary distribution for /ts/ in Ikema Ryukyuan. /s/ and /z/ are palatalized before /i/ and /j/ ([ɕ] and [ʑ], respectively). Among the obstruent consonants, singletons occur with [p b t d k g ts tɕ s z ɕ ʑ f h] in word-initial and word-medial positions. Geminate obstruents occur with [ff vv tt tts ttɕ dd ss ɕɕ zz ʑʑ] in initial and/or medial positions. Note that no single [v] occurs anywhere, and geminate [dd] occurs only in word-medial position. The vowel inventory is /a i u I/ where the phone /I/ denotes a central/apical vowel possibly with frication noise. The vowel /o/ appears in a very limited number of words. There is a length distinction for vowels, except in monosyllabic words with a singleton

consonant which are pronounced with a lengthened vowel by a bimoraic minimal word constraint. That is, a word must have at least two moras so that underlyingly monomoraic words surface as having two moras with a lengthened vowel: /ti/ [ti:] *[ti] 'hand'. As to monosyllabic words with an initial geminate consonant, they are not pronounced with a lengthened vowel (cf. /tta/ [tta] 'tongue'). This fact indicates that a geminate consonant is prosodically equivalent to a long vowel. From a theoretical perspective, only nucleus and coda have been considered as carriers of a mora (Hayes, 1989). However, recent studies revealed that onset consonants can also be moraic (Shinohara & Fujimoto, 2011; Topintzi, 2010, among others). Initial geminate consonants are regarded as having a mora on the onset in Ikema. Our study will provide durational evidence for moraicity of the geminate consonants in addition to phonological considerations. Moraic structure of words with an extra-long initial nasal consonant will be also discussed.

We take Tokyo Japanese as a point of reference because it also has a distinction between geminate and singleton obstruents: /toppa/ 'breakout', /kitte/ 'stamp', /kissa/ 'tea drinking', /matt̚ca/ 'ground green tea'. The phonetic difference between singleton and geminate obstruents in Tokyo Japanese is mainly due to the duration of frication noise for fricatives and that of the closure phase of plosives and affricates (Han, 1962, among others). Voiced geminate obstruents appear only in recent loanwords in Tokyo Japanese and are variably devoiced (Kawahara, 2006; Matsuura, 2012). Table 15.1 presents voiceless and voiced obstruent geminates which occur in Ikema in both word-initial and word-medial positions.

Table 15.1 Geminate obstruents in Ikema Ryukyuan

	Word initial	Word medial
Voiceless	<i>tta</i> 'tongue', <i>tt̚uts̚l</i> 'cicada' <i>ffa</i> 'child', <i>ssa</i> 'grass'	<i>uttu</i> 'brother', <i>att̚ca</i> 'geta clogs', <i>ntts-a</i> 'street. TOP', <i>maffa</i> 'pillow', <i>uss-a</i> 'cow. TOP'
Voiced	<i>vva</i> 'you', <i>zza</i> 'father'	<i>badda</i> 'side', <i>avva</i> 'oil', <i>tuzz-a</i> 'wife. TOP'

Analyses of real-time MRI (rt-MRI) data of Ikema Ryukyuan recorded in 2014 examined eight words by a single speaker (Fujimoto & Shinohara, 2015) and 17 words for voicing contrast by the same speaker as well as an additional speaker (Fujimoto & Shinohara, 2017a). Certain aspects of the findings reported in those studies will be examined in the current acoustic study. For instance, as estimated from the dimension of the constriction of the tongue front against the hard palate for coronal obstruents, linguo-palatal constriction for geminates was both longer in duration and also covered a larger area than for singletons. This result was similar to that reported for coronal geminate obstruents in Tokyo Japanese (Kochetov & Kang, 2013) and other languages (e.g., Ridouane, 2010). The longer and firmer constriction in articulation should result in longer frication noise for fricatives, and longer closure duration for plosives and affricate geminates. Concerning the voicing of voiced geminate obstruent [z], pharyngeal expansion, which facilitates vocal fold vibration (Perkel, 1969, among others), was observed during the articulation of /zz/ but not during voiceless /ss/. Thus, we expect a clear acoustic evidence of voicing during voiced obstruents of Ikema Ryukyuan. Another observation was a faster transition from coronal obstruents to the following vowel for geminates than for singletons, such as in /tta/ [tta] vs. /ta/ [ta:]. This may cause acoustic outputs, such as VOT, to differ between geminate and singleton.

MRI data suggest that plosive and affricate geminates have longer closure and fricative geminates have longer frication, clear voicing of voiced obstruents, and a possible VOT

difference between singletons and geminates. This is supported by acoustic data in Fujimoto and Shinohara (2013), which reported duration and voicing of word-initial obstruent singletons and geminates (/s/ vs. /ss/, /t/ vs. /tt/, and /z/ vs. /zz/) uttered by a speaker of Ikema Ryukyuan. As in Tokyo Japanese, frication noise was longer in geminate fricatives, with closure duration longer for the plosives. The study reported a full voicing of the initial voiced geminate fricative /zz/ [ddz] and a shorter VOT for voiceless geminate plosive /tt/, as compared to singleton /t/. In another acoustic study with a single token by a single speaker by Matsuura (2012), word-medial voiced geminate [vv] was fully voiced in Ikema Ryukyuan. The current paper makes an original contribution, compared to Matsuura (2012) and Fujimoto and Shinohara (2013), by using multiple speakers, a wider range of consonants in word medial as well as word initial positions.

In addition to geminate obstruents, this paper treats nasal geminates. Two kinds of nasal geminate stops occur in Ikema (Table 15.2). One is an ordinary voiced geminate appearing in both word-initial and medial positions. The other is a ‘half voiceless’ nasal in initial position, that is, the first part of the nasal is a voiceless fricative homorganic to the second voiced part.

Table 15.2 Geminate nasals in Ikema Ryukyuan

	Word initial	Word medial
Voiceless	<i>nna</i> ‘rope’, <i>mmu</i> ‘cloud’	none
Voiced	<i>mma</i> ‘mother’, <i>nna</i> ‘spiral shell’, <i>nn</i> ‘potato’	<i>haamma</i> ‘grandmother’, <i>kannai</i> ‘thunder’

Voiceless nasals are contrastively used in a variety of languages such as Burmese (Ladefoged, 2001) and White Hmong (Hmong Dictionary.com 2003-2018) among others. In these languages, voiceless nasals behave as a single consonant. But in Ikema, it is a part of a geminate since vowel lengthening for underlyingly monomoraic words does not occur in words such as /*nna*/ ‘rope’. This is an indication that the initial consonant is moraic. Our study shall describe some of the acoustic characteristics in order to clarify the status of this phone.

A word with a lengthened nasal stop without any vowel also occurs: [nn] ‘potato’. Combining this word with other morphemes makes an interesting three-way length contrast: for example, the non-moraic onset as in /*nada*/ ‘tears’, a moraic onset as in /*nta*/ ‘soil’, and bimoraic morpheme followed by another morpheme /*nndari*/ ‘potato soup’. We shall document durations of these words showing the importance of length distinction.

We investigate the following acoustic characteristics in Ikema Ryukyuan. Firstly, we observe whether geminate consonants show longer acoustic durations than their singleton counterparts as in Tokyo Japanese. Secondly, in order to find out acoustic voicing patterns, we observe voiced obstruents. Thirdly, we measure VOT of voiceless singleton and geminate stops to see whether VOT measurements reflect faster tongue transition after geminate consonants as observed in the rt-MRI study. Fourthly, we observe timing patterns of nasal geminates and voicing patterns of ‘half voiceless nasal geminates’. Finally, given that geminates have been shown to have longer duration than singletons, we investigate timing control: Does Ikema show timing control proportional to mora count as in Tokyo Japanese rather than to syllable count (Sagisaka & Tohkura,

1984; Kondo & Shinohara, 2003)? The paper starts with the study method, is followed by results and discussions, and concludes with a summary and future perspectives.

Method

We recorded one female and four male speakers of Ikema Ryukyuan, in their 60's and 70's at the time of recording. All participants were bilingual in Standard Japanese and Ikema Ryukyuan. We selected about 100 lexical items based on a previous study of this dialect by Kibe (2012). Test words in Ikema dialect and their translations in Standard Japanese were prepared as a written list. The speakers were asked to translate each word presented orally in Standard Japanese by the experimenter into Ikema dialect. Three of the participants were asked to pronounce the word three times in isolation and three times in a frame sentence, *uryaa __ do* /*urjaa__do*/ 'That is __'. The other two participants at the top end of the age range pronounced each word once in the following format: __, *uryaa __ do*, where the word before the comma is produced in isolation. They were asked to keep the tempo as constant as possible and not to make a pause within the sentence during the production. In the latter format, a short pause was inserted between the word (in isolation) and the frame sentence. The difference in format was due to availability of the speakers. Speakers at times gave some of the items with different forms from the expected ones, which resulted in some variability of test words among participants. Utterances were recorded using a Sony PCM-D50 recorder with integrated microphones at a sampling rate of 48Hz, 16bits. Recording took place at the speaker's house in the Nishihara quarter of Miyako Island in 2011 for four speakers and at a recording room in the University of Kyoto in 2014 for one male speaker. Two of the speakers were participants of the MRI study in 2014. Among the collected data, we used relevant word sets suitable for examining duration and voicing. Since we used only real words, word pairs were constructed as minimally different as possible; however, not all possible combinations were available. In such cases, near-minimal sets were used. We analysed words in isolation using Praat (Boersma & Weenink, 2016). The main reason for using the words in isolation, even though the timing controls are expected to be less homogeneous than words in a frame sentence, is that this study is complementary to our previous MRI study of Ikema geminate consonants (Fujimoto & Shinohara, 2015, 2017a), where recording conditions disfavour longer sessions with a frame sentence. Another reason is that the Ryukyuan syntax allows a bare word form to stand in phrase initial position. Thus, it is worth considering acoustic cues in this context. The number of tokens per word used in this study are generally eleven (three tokens each by three speakers and one token each by two speakers), with variation due to either extra or failed tokens, which are noted. The word sets examined are introduced in the following results and discussion sections.

Results and discussion

Duration patterns of geminate obstruents

Because we could not find minimal pairs of geminate and singleton fricatives, we made comparisons between the geminate /ss/ in /ssa/ [ssa] 'grass' and the singleton /s/ in /sata/ [sata] 'sugar', and also between /ff/ in /ffa/ [ffa] 'child' and /f/ in /fau/ [fau] 'to eat' (or in /fai/ [fai], a variant by one speaker). All are two mora words. According to duration measurements from spectrograms (see Figure 15.1), frication is longer in the geminate with fricative consonants.

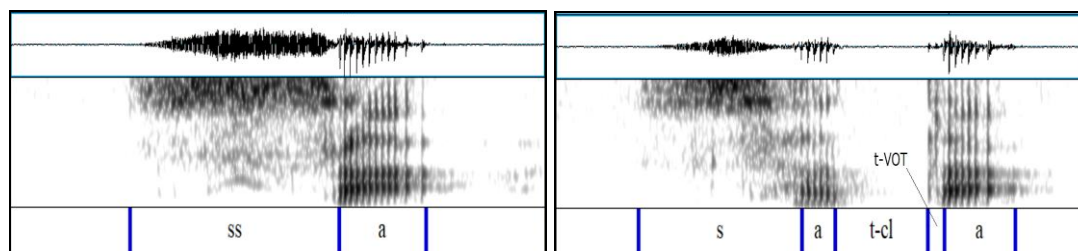


Figure 15.1 Spectrograms of /ssa/ [ssa] 'grass' vs. /sata/ [sata] 'sugar'. Frame length is 600 ms

We observed a qualitative difference in sharpness of the boundary between the frication noise and the onset of the first vowel. As can be seen in Figure 15.1, the boundary is sharper after the geminate than after the singleton. We also observed that the vowel /a/ following the fricative in /sata/ was devoiced in three tokens by two speakers, but not in /ssa/. This might suggest vowel quality differences due to the gemination of the preceding consonant. Further analysis is necessary to examine this point.

Figure 15.2 presents boxplots of the durations of singleton and geminate /f/ ([f] and [ff]) and /s/ ([s] and [ss]). The averaged durations with SD in parentheses followed by the number of consonants are as follows: for /f/ 90 ms (SD 17ms) (N=8); for /ff/ 178 ms (SD 14 ms) (N=11); for /s/ 176 ms (SD 17 ms) (N=8); and for /ss/ 211ms (SD 14 ms) (N=12). The result of ANOVA with consonant (either /s/ or /f/) and gemination (either singleton or geminate) as independent variables and consonant duration as dependent variable showed that consonant ($F(1,35)=15.362, p<.000$) and gemination ($F(1,35)=16.296, p<.000$) were both significant but interaction was non-significant ($F(1,35)=2.962, p=0.094$). Thus, fricative geminates are significantly longer than singletons.

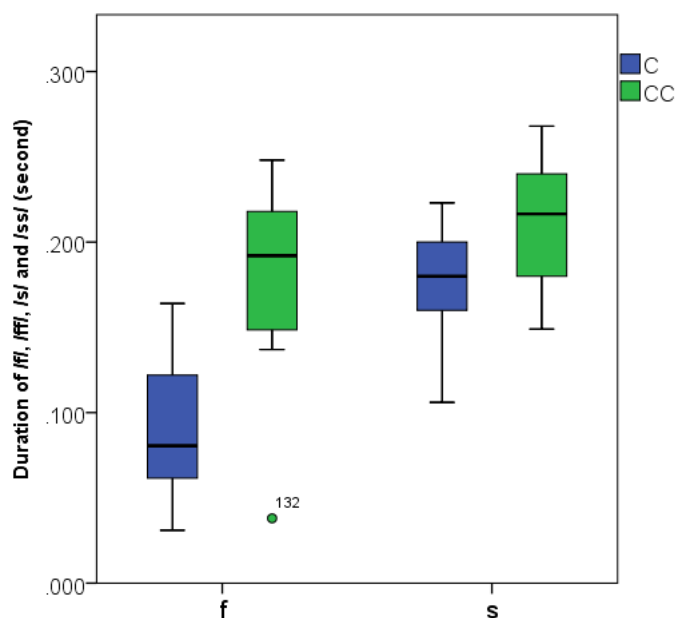


Figure 15.2 Boxplots of the durations of singleton and geminate /f/ ([f] and [ff]) and /s/ ([s] and [ss])

Plosives and affricates are also longer in geminates especially in the closure period. We compared the averaged closure durations of /ts/ [tʃ] in /atsa/ [atʃa] 'tomorrow', /tts/

[ttɕ] in /attsɑ/ [attɕɑ] ‘geta clogs’, /d/ [d] in /nada/ [nada] ‘tear’, and /dd/ [dd] in /baddɑ/ [baddɑ] ‘side’. Figure 15.3 shows boxplots of the closure duration of singleton and geminate /ts/ ([tɕ] and [ttɕ]) and /d/ ([d] and [dd]). The average duration of the closure period, SD in parentheses, and the number of tokens of the consonants were 63 ms (SD 19 ms) (N=12) for /ts/, 180 ms (SD 44 ms) (N=11) for /tts/, 49 ms (SD 8 ms) (N=11) for /d/, 171 ms (SD 28 ms) (N=11) for /dd/. Results of ANOVA with consonants (either /(d)d/ or /(t)ts/) and gemination (either singleton or geminate) as independent variables, and the closure duration as dependent variable, showed that closure duration was significantly longer in geminates than in singletons ($F(1, 41)=208.859, p<.000$), but consonants and interaction showed no significance. Thus, we find differences of acoustic closure duration for geminate segments compared to their singleton counterparts in these plosive and affricate pairs.

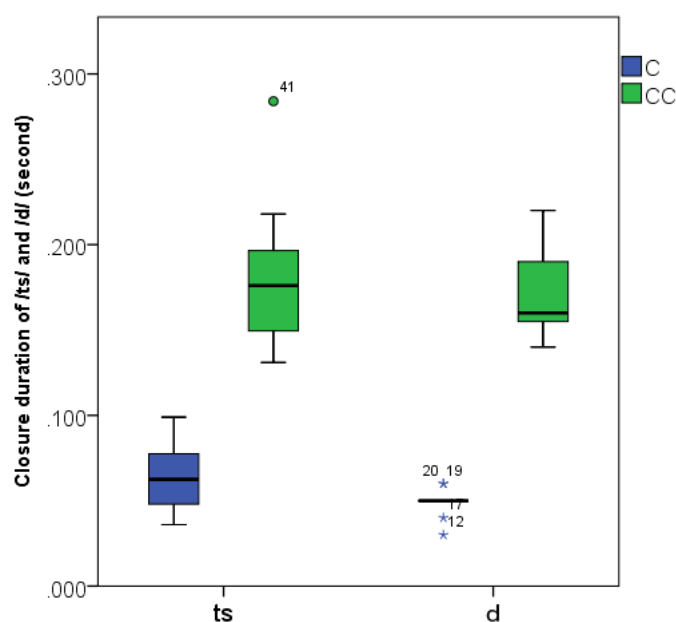


Figure 15.3 Boxplots of the closure duration of singleton and geminate /ts/ ([tɕ] and [ttɕ]) and /d/ ([d] and [dd])

Duration differences had been previously observed for a small set of consonants (/s/ vs. /ss/, and /z/ vs. /zz/ in isolation, and /t/ and /tt/ uttered in a frame sentence) by Fujimoto and Shinohara (2013). The current study extended the findings of geminates being acoustically longer than singleton counterparts to a wider variety of consonants. More precisely, geminate fricatives [ss] and [ff] in initial position showed longer frication noise. Geminate plosive [dd] and affricate [ttɕ] in word-medial position showed longer closure duration. These results corroborate previous studies showing longer frication noise in geminates [ss] and [zz] and longer closure duration in the voiceless geminate stop [tt]. The results on obstruent duration indicate that phonological contrast between geminate and singleton consonants is realized by phonetic duration differences in Ikema Ryukyuan, as in Tokyo Japanese.

Full voicing in voiced geminate obstruents

We examined voicing patterns of the words: /baddɑ/ ‘side’, /iddai/ ‘cough’, /vva/ ‘you’, /kuvva/ ‘calf’, /zza/ ‘father’, /zzu/ ‘fish’ and /zI/ [zI:] (/I/ = a central/apical vowel with frication noise) ‘soil’. The full voicing was observed in most of the voiced geminate obstruents for 75 tokens (seven words * three tokens * three speakers + six words * one

token * two speakers). Voiced geminates presented voice bars during the frication for all of the fricatives and during closure and release for plosive /d/ of all, except one, tokens mentioned below and two tokens by two speakers pronounced with a variant /judai/ for /iddai/. In addition, a long pre-voicing often preceded initial voiced geminate consonants, as illustrated in the left-side of the spectrogram of [v] in /vva/ [vva] ‘you’ in Figure 15.4. Pre-voicing without frication noise in the high frequency area occurred with seven tokens out of eleven among five speakers, duration of which was 81 ms on average (SD 37 ms). For word-medial voiced plosives, voicing continued through the whole closure phase as illustrated in the right-side spectrogram of /badda/ [badda] ‘side’. This is true for most of the eleven tokens of /badda/ with an exception of a female speaker where [dd] was partially devoiced before release.

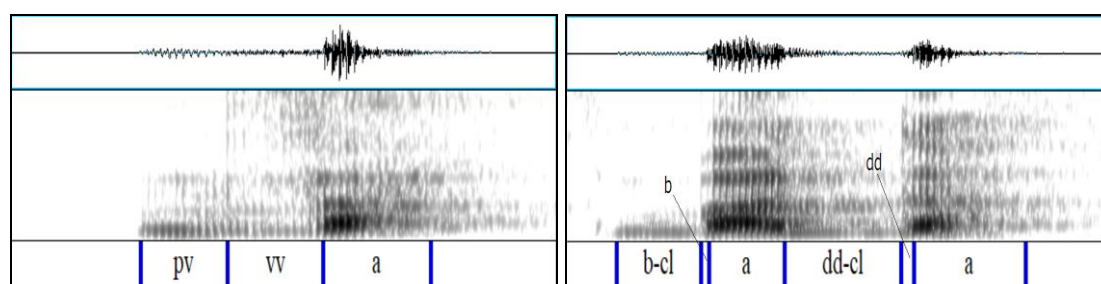


Figure 15.4 Spectrograms of /vva/ [vva] ‘you’ (left) and /badda/ [badda] ‘side’ (right). Frame length is 580ms and 700 ms. pv for pre-voicing, cl for closure

The voicing pattern differs from Tokyo Japanese. Voiced geminate obstruents are used only in a marginal vocabulary in Tokyo Japanese and they are reported to be devoiced. Avoiding voiced geminate obstruents seems to be a cross-linguistic tendency (Jaeger, 1978; Kirchner, 2000). Although voicing throughout geminate obstruents is physiologically challenging (Rothenberg, 1969; Westbury, 1983), articulatory settings enabling such production are partly revealed in rt-MRI studies. Speakers expand the pharynx during voiced geminates presumably to initiate and to keep the voicing (Fujimoto & Shinohara, 2015, 2017a). The current study found that initial voiced fricative geminates [vv] and [zz] are fully voiced with a voice bar preceding them, and the voiced geminate plosive [dd] is generally fully voiced during the closure. The rich inventory of voiced geminates in the lexicon seems maintained by the clear voicing contrast between the voiced and the voiceless counterparts.

VOT difference in the voiceless alveolar singleton and geminate plosive

A VOT difference between geminate and singleton was observed in the voiceless plosive. As described above, only the alveolar plosive shows a contrast between singleton and geminate among voiceless plosives. Figure 15.5 shows the acoustic waveforms and spectrograms of /ti/ [ti:] ‘hand’ and /tii/ [tti:] ‘pipe’. A voiceless geminate plosive [tt] has a shorter lag. Singleton stops have noticeably long VOT.

We examined the VOT differences of [t] between /tta/ [tta] ‘tongue’ and /ta/ [ta:] ‘rice field’, and [t] between /tii/ [tti:] and /ti/ [ti:]. Note that the vowels in /ta/ and /ti/ are lengthened by the bimoraic minimality constraint. Each word was uttered in isolation by five speakers. Figure 15.6 shows boxplots of VOT of these four cases. VOT is on average 45 ms (SD 17 ms) for /ta/, 11 ms (SD 5 ms) for /tta/, 52 ms (SD 6 ms) for /ti/, and 17 ms (SD 4 ms) for /tii/. ANOVA with word (i.e., /ta/ or /ti/) and gemination (i.e., singleton and geminate) as independent variables, and the duration of VOT as dependent variable, showed that durations of VOT differ significantly depending on

gemination ($F(3, 39)=1440.965$, $p<.000$), but the word ($F(3, 39)=4.871$, $p=.033$) and interaction ($F(3, 39)=0.12$, $p=.913$) were non-significant. Bonferroni's post-hoc test showed that VOT in geminate /tt/ is significantly shorter than single /t/.

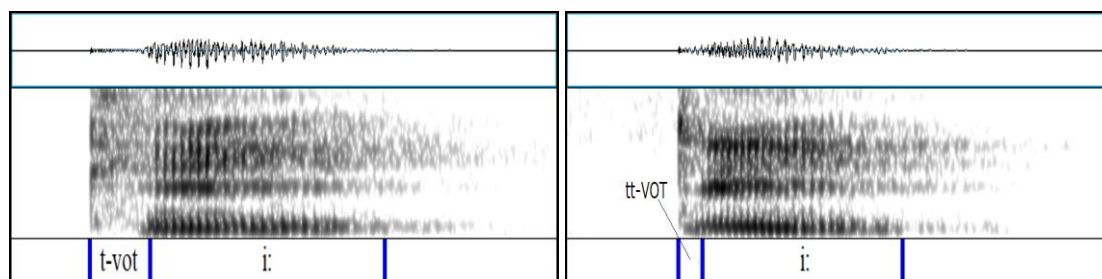


Figure 15.5 Spectrograms of /ti/ [ti:] 'hand' (left), /ttii/ [tti:] 'pipe' (right). Frame length is 500ms

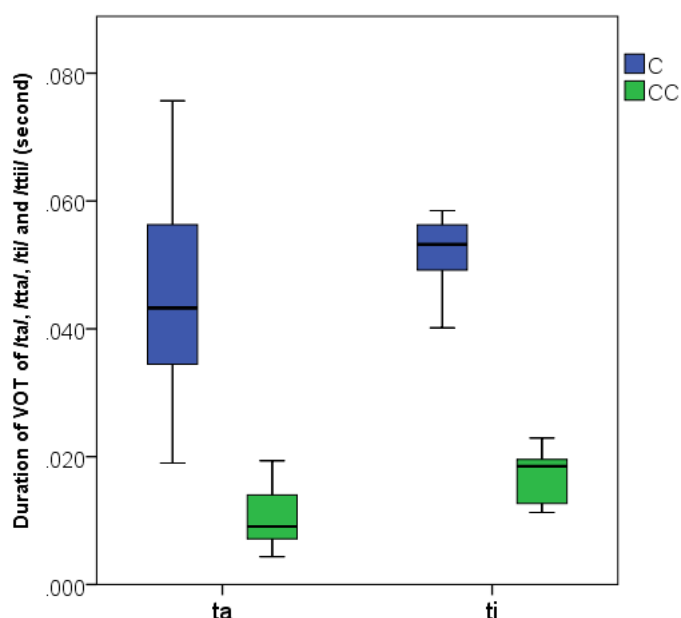


Figure 15.6 Boxplots of VOT of singleton and geminate /ta/ [ta:] and /tta/ [tta] and /ti/ [ti:] and /ttii/ [tti:]

Voiceless plosives in Ikema Ryukyuan differ between singletons and geminates in terms of VOT. We examined /t/ vs. /tt/ in initial position with two minimal pair words. Voiceless singleton plosives in both pairs had longer aspiration than their geminate counterparts. This is distinct from Tokyo Japanese where no difference of VOT in this direction has been found (Han, 1994; Hirata & Whiton, 2005). The rt-MRI study showed faster transitions from the geminate plosives toward the following vowel target than was seen for singletons (Fujimoto & Shinohara, 2015). A shorter VOT must be an acoustic consequence of this faster transition. The VOT difference might signal whether the voiceless stop is a singleton or a geminate, since silent closure duration cannot be a cue in word-initial position (note that Ikema dialect does not have a length contrast of labial plosives, which could have been visually cued). The Ikema dialect contrasts voiceless alveolar singleton /t/ and geminate /tt/ but lacks the initial voiced geminate /dd/. Lack of /dd/ in initial position can be explained by its phonetic similarity with /tt/. Since VOT is short after /tt/, it would be easily perceptually confused with /dd/ if

both occurred in initial position. However, in word-medial position, other cues such as closure duration differences before voiceless and voiced plosives might be available for perception, so that the voicing contrast can be maintained. This kind of result can be considered from the perspective of phonological evolution of the dialect.

Duration and acoustic patterns of geminate nasal consonants

This sub-section presents some acoustic characteristics of word-initial nasal consonants. We focus on the three-way length distinction of the voiced alveolar nasal stop on one hand and on the ‘half voiceless geminates’ on the other.

There is a three-way length distinction of nasal stops in word initial position. We compared the duration of a near minimal triplet: /nnta/ ‘nuts’, /nta/ ‘soil’ and /nada/ ‘tears’ along with a word composed only of a nasal consonantal sound /n/ [nn] ‘potato’, as pronounced by five speakers. Figure 15.7 shows the cumulative bar chart of the segments in words *nn*, *nnta*, *nta*, and *nada* where nasal consonants are presumably bi-moraic, bi-moraic, moraic onset, and non-moraic onset, respectively.

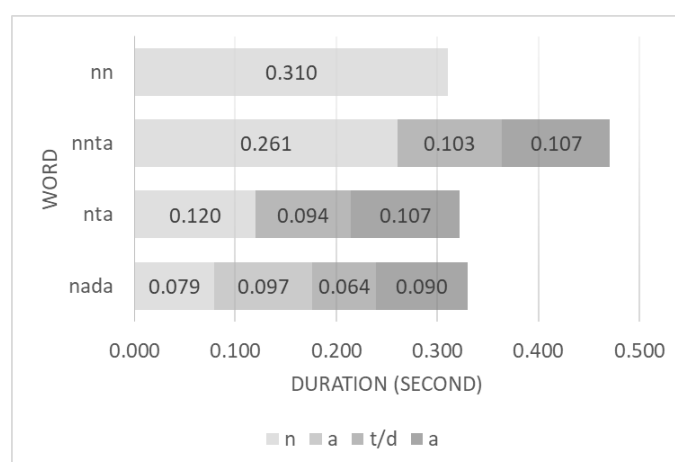


Figure 15.7 Segment durations in /n/ [nn] ‘potato’, /nnta/ ‘nuts’, /nta/ ‘soil’ and /nada/ ‘tears’ by five speakers

The duration of the nasal consonants in /nada/, /nta/, /nnta/ and /nn/ are compared in Figure 15.8. The average durations with SD in parentheses of nasal consonants ([n] or [nn]) of *nada*, *nta*, *nnta* and *nn* were 79 ms (SD 42 ms) (N=12), 120 ms (SD 33 ms) (N=12), 261 ms (SD 60 ms) (N=13), and 310 ms (SD 42 ms) (N=11), respectively. ANOVA with word (i.e., the type of nasal consonant) as independent variable and the duration of nasal consonants as dependent variable showed that durations of nasal consonants differ significantly depending on the word ($F(2, 34)=52.633$, $p<.000$). Bonferroni’s post-hoc test showed that duration of the nasal consonants differs significantly between the members of the pairs, *nada-nnta* ($p<.000$), *nada-nn* ($p<.000$), *nta-nnta* ($p<.000$) and *nta-nn* ($p<.000$), but not between the members in *nada-nta* ($p=.116$) or in *nnta-nn* ($p=.068$). Thus, the bimoraic nasal consonant is significantly longer than non-moraic onset nasal and single moraic nasal consonants in word initial position. However, the moraic nasal onset is not significantly longer than the non-moraic nasal onset.

As is clear from Figure 15.7, the three-mora word *nnta* is longer than the two-mora words *nta*, *nada* and *nn*. Figure 15.9 shows boxplots of the word durations of /nada/, /nta/, /nnta/ and /n/ ([nn]). The average word durations with SD in parentheses of

nada, *nta*, *nnta* and *nn* were 325 ms (SD 40 ms) (N=12), 320 ms (SD 43 ms) (N=12), 469 ms (SD 80 ms) (N=13), and 310 ms (SD 42) (N=11), respectively. ANOVA with word as independent variable and word duration as dependent variable showed that word durations differ significantly depending on the word ($F(2,34)=26.856$, $p<.000$). Bonferroni's post-hoc test revealed that word durations significantly differ between the members of the pairs, *nada-nnta* ($p<.000$) and *nta-nnta* ($p<.000$), but does not differ between the members in *nada-nta* ($p=1.000$), *nada-nn*, and *nta-nn* ($p=1.000$). Thus, the durational difference of words reflects the moraic status of the nasal consonants.

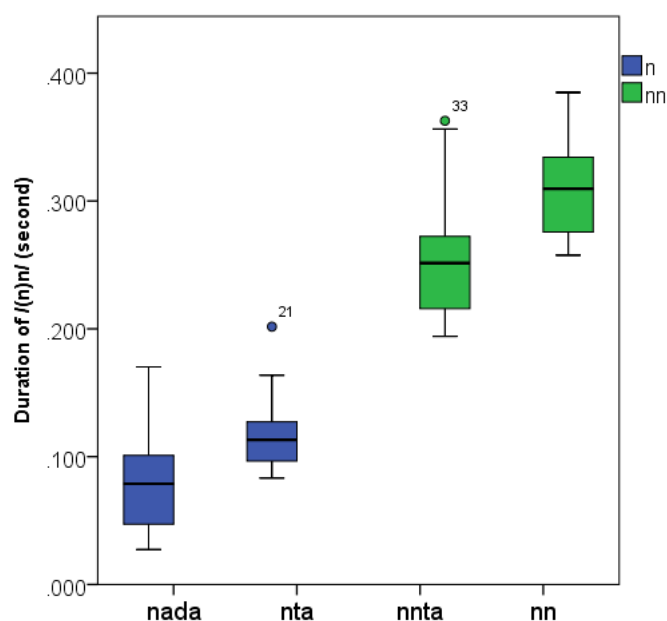


Figure 15.8 Boxplots of the duration of /n/ in /nada/, /nta/, /nnta/ and /nn/

The spectrogram of *nn* [nn] 'potato' in Figure 15.10 shows characteristics of nasal formants throughout (cf., Figure 15.11). This means that the word is produced without a vowel nucleus, but the nasal consonant itself is the nucleus. Thus, [nn] is not only moraic but is also syllabic in this word, and presumably also in the word /nnta/ above.

In the voiced nasal word set, the moraic nasal onset in /nta/ 'soil' did not show statistically significant durational differences from [n] in the non-moraic onset in /nada/ 'tears'. In the form like [nta], we know that /n/ is moraic because otherwise the bimoraic word minimality should have lengthened the vowel. The theoretical length difference of these two nasal stops seems to be compensated by the other segments to achieve similar word durations. It is known that each moraic element is not isochronous due to intrinsic segmental duration, but rather, the duration differences are adjusted by all segments at the word level in Tokyo Japanese (Han, 1994; Port, Dalby, & O'Dell, 1987). Note also that in the word /nta/, the duration of the whole sequence /nt/ would correspond to a geminate consonant. Thus, the comparison is not between singleton and geminate consonants but between moraic and non-moraic onsets. Although the moraic status of the initial nasals has not been fully investigated in previous work, our result suggests that it has moraic characteristics. As to /nnta/, the initial [n] is more than twice as long as the one in /nta/, on average. We do not know the morphological structure of this word. Since its whole word duration is 1.5 times longer than /nada/, it is natural to consider that the initial part has two mora lengths. There are other words such as /nndari/ 'potato soup' or /nnpura/ 'digging stick', which have the same long [nn] in initial position. These words are compounds of /n/ [nn] 'potato' and /dari/

'soup' or /pura/ 'digging', respectively. We know that /n/ is lengthened by bimoraic minimal word constraint. It might well be the case that the bimoraic constraint is active within the domain of morpheme, not of prosodic word, in Ikema Ryukyuan. This long [nn] is not only moraic but it is even bimoraic; thus, we leave the phonemic transcription with the double /nn/ in these words to distinguish it from the single moraic /n/ in word initial position. The phonological representation of the surface bimoraic [nn] in /nnta/ should be confirmed with more examples of compound words.

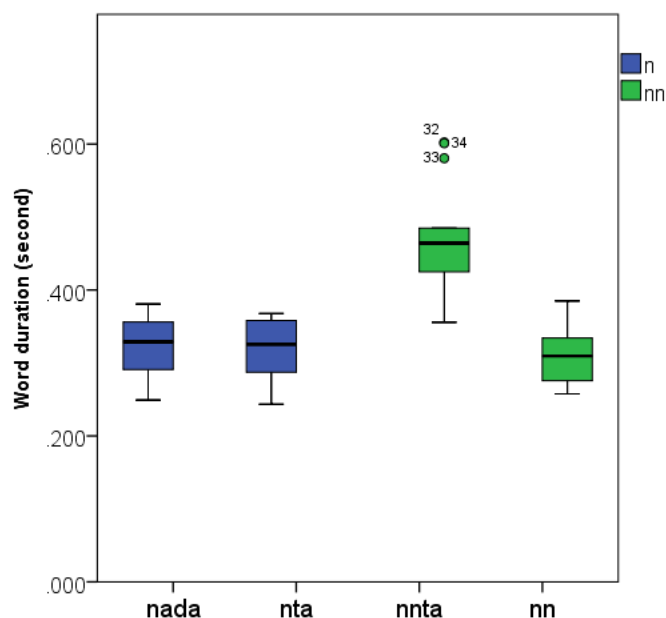


Figure 15.9 Boxplots of the word durations of /nada/, /nta/, /nnta/ and /n/ ([nn])

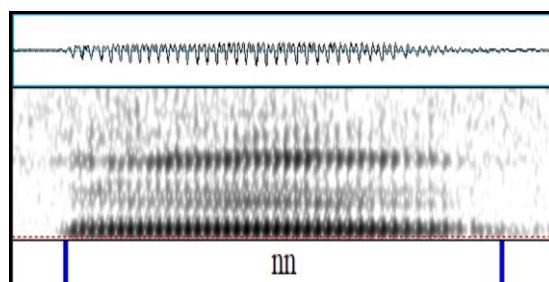


Figure 15.10 Spectrogram of /n/ [nn] 'potato'. Frame length is 400ms

As briefly presented in the description of Ikema Ryukyuan, place oppositions occur between voiced nasal [m] and [n], and between voiceless nasals [ṃ] and [ṅ] in word initial position. However, [ṃ] and [ṅ] occur only before their homorganic voiced nasal stop counterparts [m] and [n]. Therefore, the voiceless nasals are considered to be the first part of 'half voiceless nasal geminates', differing in voicing between the first part and the second part. Pairs of words such as [nna] 'yesterday' and [ṅna] 'rope' differ in voicing, while pairs such as [mma] 'mother', [nna] or [ṃmu] 'cloud', and [ṅnu] 'horn' differ in place of the nasal stop.

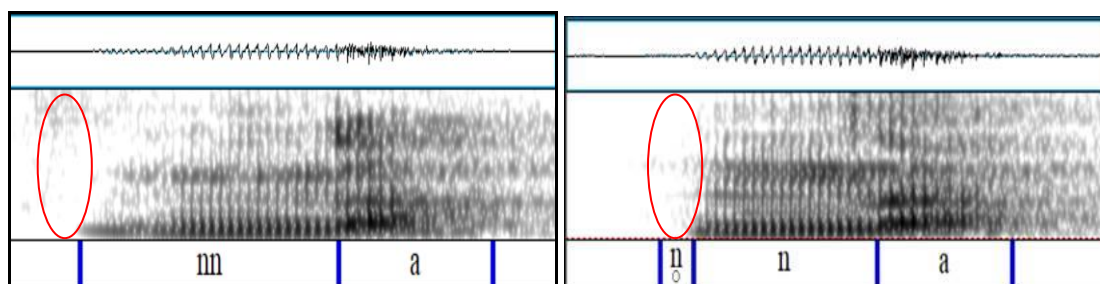


Figure 15.11 Spectrograms of /nna/ 'spiral shell' (left) and /ŋna/ 'rope' (right). Frame length is 400ms

In the spectrograms in Figure 15.11, voiceless noise preceding the voiced nasal [n] is seen for both words (circled in the spectrograms). Some formant structure similar to the voiced part is observed in the [ŋ] portion of the one on the right, while the noise preceding /nna/ is more random in the one on the left.

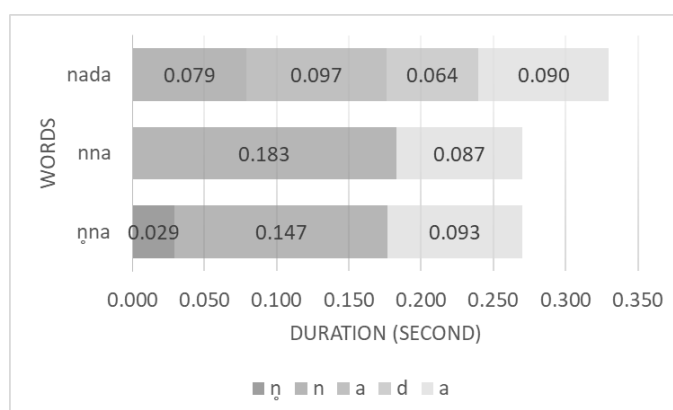


Figure 15.12 Segment durations of /nada/ 'tears', /nna/ 'spiral shell' and /ŋna/ 'rope' by five speakers

Average durations of each part of these words uttered by five speakers are shown in Figure 15.12. All are two-mora words. The words /nna/ and /ŋna/ differ in the first moraic nasals: voiced in the former and voiceless in the latter.

Figure 15.13 shows boxplots of duration of the nasal parts of /nada/, /nna/ and /ŋna/. The average durations with SD in parenthesis of nasal consonants, [n] in *nada*, [nn] in *nna*, [ŋn] in *ŋna*, were 79 ms (SD 42 ms), 183 ms (SD 18 ms), and 177 (SD 21 ms), respectively. ANOVA with word (i.e., the type of nasal consonants) as independent variable, and their durations as dependent variable, showed that the durations of nasal consonants differ significantly depending on the word ($F(2, 31) = 45.593, p < .000$). Bonferroni's post-hoc test showed that nasal consonants significantly differ between *nn-n* ([nn] in *nna* and [n] in *nada*), ($p < .000$), and between *ŋn-n* ([ŋn] in *ŋna* and [n] in *nada*) ($p < .000$) but do not differ between *nn-ŋn* ($p = 1.000$). Thus, both voiced and 'half voiceless' geminate nasals are significantly longer than the singleton nasal onset.

Although they are all two moras, word duration of *nada* is longer than the words containing nasal geminates. Figure 15.14 shows boxplots of the word duration of /nada/, /nna/ and /ŋna/. Each of the averaged word durations with SD in parenthesis was 325 ms (SD 40 ms) ($N = 12$) for *ŋna* [ŋna], 270 ms (SD 26 ms), ($N = 11$) for *nna*, and 270 ms (SD 20 ms), ($N = 11$) for *nada*. ANOVA with word as independent variable and word duration as a dependent variable showed that word durations differ significantly

depending on the word ($F(2,31)= 13.160, p<.000$). Bonferroni's post-hoc test revealed that word durations significantly differ between $\eta na-nada$ ($p<.000$) and between $nna-nada$ ($p<.000$), but does not differ between $\eta na-nna$ ($p=1.000$). Thus, the duration of the two syllable word with a nasal onset is significantly longer than two mora words with a geminate nasal onset.

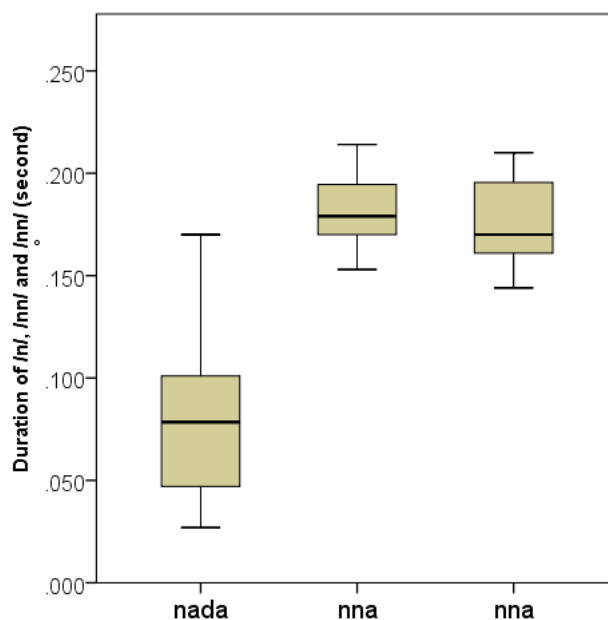


Figure 15.13 Boxplots of duration of / $(n)n$ / or / ηn / of / $nada$ /, / nna / and / ηna /

In the word set with initial voiced and half voiceless nasal geminates, the durations of geminate consonants ([nn] and [ηn]) of nna , and ηna were on average more than twice as long as / n / [n] in $nada$. Thus, in these one-syllable words (/ nna / and / ηna /), two mora lengths must be signalled by the duration of the geminate. Unlike nta , the whole word durations of nna and ηna did not reach that of $nada$. This result is counter to a strict moraic duration control. However, in the next section about the overall patterns of word durations, we shall see that even though complete isochrony is not attained, overall duration increases in proportion to mora count.

The proportion of the voiceless nasal to the entire geminate is remarkably short if we consider it as a moraic segment. However, it is probably long enough to signal the voicelessness of the whole 'half voiceless nasal geminate'. Further study is essential to understand the cues distinguishing voiced and voiceless nasals. Potential cues may be pitch patterns and intensity. Note, in passing, that when the words with initial voiceless nasals are used phrase-internally, more acoustic cues of voicelessness are present since the preceding sound is necessarily a voiced sonorant.

Overall patterns of whole word durations

In the preceding sections, we have identified length differences between singleton and geminate consonants in several (near-) minimal pairs and observed their duration patterns. Variability in duration according to segment types and contexts among the moraic elements was also seen. In this section we examine duration of a variety of words in Ikema Ryukyuan, testing whether they behave according to their mora count or syllabic count. We measured the word duration of the test words of two speakers. The test words shorter than four moras were classified into four groups according to the following criteria: a consonant immediately preceding another consonant (i.e., a first

half of a geminate or the nasal segment of a *nt/nts* cluster) or a light syllable counts as one mora, while a combination of an initial geminate (or an onset *nt/nts* cluster) plus a short vowel, a long vowel, or a vowel followed by a placeless nasal /N/ counts as two moras, and is a heavy syllable. Table 15.3 shows the classification of the 25 test words into four groups according to their syllable/mora breakdown. Most of the test words were produced by two speakers except that the words *isagu* and *suzata* were produced by one (different) speaker and *akaN* was produced as its variant form, *aka*, by one speaker.

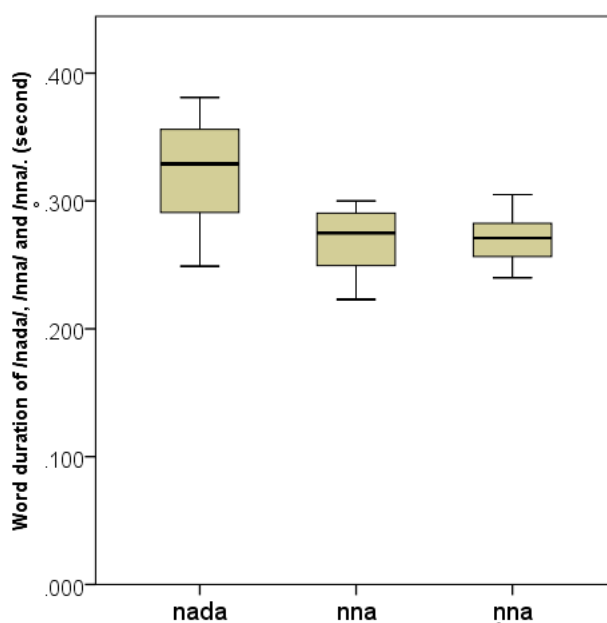


Figure 15.14 Boxplots of the word duration of /nada/, /nna/ and /ɲna/

Table 15.3 Ikema words differing in syllable and mora counts for duration comparison

3 syllables/ 3 moras	<i>isagu</i> 'cough', <i>fuzata</i> 'brown sugar', <i>suzata</i> 'white sugar'
2 syllables/ 3 moras	<i>akaN</i> 'dirt', <i>maffa</i> 'pillow', <i>nnutsl</i> 'life', <i>nuuma</i> 'horse', <i>attsa</i> 'geta', <i>adaN</i> 'a type of plant', <i>ffatsl</i> 'hoe', <i>zzaku</i> 'oar', <i>nnta</i> 'nut'
2 syllables/ 2 moras	<i>munu</i> 'thing', <i>naba</i> 'dirt', <i>nada</i> 'tear', <i>sata</i> 'sugar', <i>atsa</i> 'tomorrow', <i>aka</i> 'dirt'
1 syllables/ 2 moras	<i>miN</i> 'ear', <i>ɲna</i> 'rope', <i>ssa</i> 'grass', <i>ɲmu</i> 'cloud', <i>nta</i> 'soil', <i>ntsl</i> 'road', <i>zl</i> [zI:] 'soil'

Each word was produced three or four times by each of the speakers. The results of the two speakers are shown in Figure 15.15. Word durations were 497 ms (SD 65 ms) (N=11) for 3 syllable/3 mora words, 451 ms (SD 81 ms) (N=54) for 2 syllable/3 mora words, 344 ms (SD 71 ms) (N=32) for 2 syllable/2 mora words, and 345 ms (SD 50 ms) (N=42) for 1 syllable/2 mora words. ANOVA with mora count and syllable count as independent variables and word duration as dependent variable showed that mora count was a significant factor for word duration ($F(1,135)=43.879$, $p<.000$, but not syllable count (interaction of mora and syllable is not applicable as it has zero degrees

of freedom). The results, thus, indicate a moraic rather than syllabic timing in this dialect.

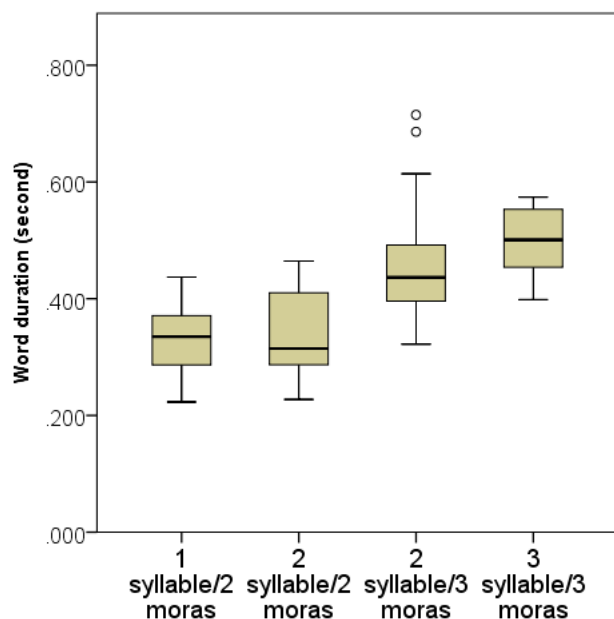


Figure 15.15 Three mora- versus two mora- word durations in second uttered in isolation by two speakers. Error bars show the standard deviation

Given that our examinations of singleton and geminate consonants showed significant duration differences, we compared duration of words classified with numbers of syllables on the one hand and with the number of moras on the other. The words differing in number of syllables behaved similarly when the number of moras was the same. For instance, CVCCV (two syllables/three moras) words (e.g., /maffa/ ‘pillow’) showed a more similar duration to CVCVCV (three syllables/three moras) words (e.g., /fuzata/ ‘white sugar’) than to CVCV (two syllables/two moras) words (e.g., /sata/ ‘sugar’). The result of the timing investigation indicated that speakers’ utterances are based on mora rhythm, at least at the word level, since mora count had a significant effect on the word duration whereas syllable count did not always. Speakers uttered the test words incited by oral translation; thus, there is no reason to consider any influence from the writing system. Moreover, Ikema dialect is largely an oral language with not even a standard way of writing with Japanese syllabary in the dialect. Since Ikema Ryukyuan seems to operate on moraic timing, longer duration of geminate consonants must reflect its phonological moraicity.

Summary and future perspectives

The Ikema dialect of Miyako Ryukyuan presents a number of interesting sounds, such as initial voiceless and voiced geminate consonants, ‘half voiceless nasal geminates’, optional devoicing of low vowels, and a fricative vowel. Among them, we documented durational and other acoustic characteristics of geminate obstruents and nasals. In the phonological description of Ikema Ryukyuan, the geminate consonants are considered to be moraic (Pellard & Hayashi, 2012). However, phonetic realizations of geminate consonants have not been fully described. Our previous study of geminate obstruents in Ikema Ryukyuan using rt-MRI made the following observations: 1) longer and firmer

constrictions for geminates, 2) pharyngeal expansion for voiced geminate obstruents and 3) faster movement of articulators from a voiceless geminate onset to the following vowel (Fujimoto & Shinohara, 2015, 2017a). The current study of five native speakers compared durations of geminate consonants with those of singletons with several (near)-minimal pair words, including those involving initial geminates of oral and nasal stops and fricatives, and identified the acoustic correlates of the previously reported articulatory characteristics, and also reported on related issues.

In particular, we observed voicing during frication of two types of fricatives, /vv/ and /zz/, and during the closure phase of voiced plosive /dd/. Another aspect related to voicing is the VOT difference of voiceless plosives /tt/ and /t/. Since the rt-MRI study indicated a faster articulator movement after the geminate /tt/, we expected some kinds of acoustic correlates accompanying it. The present study found in two minimal word pairs a shorter lag for /tt/, clearly different from the lag for the singleton /t/. As to nasal stops, we identified an equivalent length between regular initial nasal geminates and the ‘half voiceless nasal geminates’. The latter type is comprised of a voiceless nasal part followed by a voiced part. Although the voiceless part does not fill half the length of a geminate nasal, the whole sequence lasts as long as a voiced geminate nasal stop. Among nasal geminate types, there is also a nasal stop without a vowel nucleus, of which the duration is equivalent to two-mora words. In addition, examination of sets of test words of two of the speakers shed light on whether the mora or the syllable is the unit of timing control at the word level in this dialect.

Future directions may include detailed acoustic studies of the nasal consonants, especially the voiceless /ŋ̥/ (/ŋ̥/ and /m̥/), since the current study confirms that it contrasts with the voiced nasal /N/ (/n/ and /m/) in geminates. A new articulatory study is to be planned in order to investigate these nasal consonants. Perceptual studies are also needed to better understand how the speakers of Ikema distinguish voiceless nasals from voiced ones, as well as singleton plosives from geminate initial ones. Acoustic studies of the pitch-accent are also essential as accent types and their patterns are issues of debate in Ikema, as well as in other Miyako Ryukyuan dialects. As the number of fluent speakers is decreasing, it is urgent to carry out both qualitative and quantitative studies of these dialects.

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