An instrumental analysis of the two tone system in Ikema Ryukyuan

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1. Introduction

Ikema is one of the subdialects of Miyako Ryukyuan, spoken on Ikema island, in Sarahama on Irabu island, and in Nishihara on Miyako island. It has been reported that Ikema has the two tone pattern system (a.k.a. *nikei-akusento*) in which two tonal classes (Type A and Type B in this study) are lexically distinguished (e.g. [3], [4]). Miyako Ryukyuan is an endangered language and most of the fluent speakers of Ikema are in the 60's or older. The clear distinction of the two tonal patterns, however, can be clearly observed in the speech of all the fluent speakers, in opposition to the observations made in Hirayama [4] .

We have shown elsewhere that Ikema exhibits a tone patterning considerably different from that of other varieties of Japanese known to have the two tone pattern system such as the Kagoshima and Shimabara dialects [2]. We have also shown that the pitch contour of Ikema is regulated by a non-distinctive lowering (and raising) induced by what we call the High Low (HL) alternation [6]. The HL alternation was originally proposed by Shimoji [5] in the description of Irabu, another subdialect of the Miyako Ryukyuan. This is a type of trochaic rhythm structure with the alternating pattern described with two tones H and L, each of which is associated with the metrical constituent foot of two (or three) morae. We argue that the tonal realization of Ikema can only be described by combining (i) lexical tone classes and (ii) the HL alternation pattern, both of which are independently motivated.

Previous studies of surface tonal patterns of Ikema words fail on two counts: they did not take the non-distinctive lowering into account and they failed to identify the place where the lexical distinction appears. We have shown that the tone distinction appears at the rightmost position of the word [2]. Specifically, Type A words make the right-adjacent element realize in L tone while Type B words make it realize in H tone. This lexical tone distinction can be identified easily especially when the word is followed by another element (e.g. particles or verbal suffixes). For example, the Type A word *in* 'dog' followed by a particle *mai* 'also' is realized as *in-mai* /H-L/ while the Type B word *in* 'sea' is realized as *in-mai* /H-H/. The tonal distinction in citation form is not as clear as in the case of particles, but we hypothesize that it might also be observed in citation form. The investigation of the actual condition of the tonal pattern in citation form is also a part of the aim of this study.

Non-distinctive lowering related to the HL alternation appears in words of four or more morae. This is so because the unit of tone assignment for HL alternation is the foot, consisting of two to three morae. The foot formation begins from the left edge of a morpheme. If there is a stray mora (mora not parsed), it is attached to the left-adjacent foot, thus each foot is two or three morae long. If a word has two or more feet, the tone H and L, in this order, are assigned from the left edge of the word. The non-distinctive HL alternation thus appears in words of four or more morae. Independent of the HL tone alternation, the lexical tone can be identified at the rightmost position of four-morae words. The HL alternation can also be seen in the concatenation of two-morae particles. That is, when two or more two-morae particles follow a word, they exhibit an alternating tone pattern. For example, *in-kara-mai* 'dog-from-also', a concatenation of *kara* and *mai* attached to *in* 'dog', a Type A word, is realized as *in-kara-mai* /H-L-H/, with a pitch fall characteristic of Type A at the word periphery, accounting for the HL tone pattern and the HL alternation is responsible for the raising of the following foot, thus the HLH pattern. When *kara-mai* is attached to *in* 'sea', a Type B word, it is realized as *in-kara-mai* /H-H-L/. Since *in* 'sea' is a Type B word, the left-adjacent element of the phonological word (PW)[1] appears in H but a fall appears after *mai* because of the HL alternation. In other words, the HL alternation in Ikema can be characterized as assigning a word-initial H tone and assigning each successive foot a tone contrasting with the previous. Lexical tones take precedence, and thus decide the actual tone pattern.

The aim of the present work is to confirm our previous descriptions, by quantitatively analyzing the speech data on the basis of the extraction of fundamental frequency (F0). In this study, we will demonstrate the contrasts as reflected in the F0 contours of nouns with two to four morae.

2. Experiment

2.1 Methods

2.1.1 Speech materials

We used a set of two-, three- and four-morae words of various syllable structures as test words. The test words are shown in Table 1. Each test word was incorporated into test phrases: X (followed by no particle), X-*mai* (followed by a two-morae particle), and X-*kara-mai* (followed by two two-morae particles), where X is a test word.

1 A phonological word (PW) is the domain of lexical tone realization. That is, the lexical tone appears at the rightmost position of PW. It consists of a lexical word optionally followed by some derivational suffixes or one mora particles. One-mora particles must be attached to the left-adjacent foot as in the case of a stray mora, because it cannot form a foot by itself. As a result, one mora particles become a part of phonological words.

Table 1: Test words.

Set	Type A	Type B
Two-morae		
Set	Type A	Type B
1	mayu 'cat'	nabi 'pan'
2	mai 'rice'	bau 'stick'
3	in 'dog'	in 'sea'
4	zzu 'fish'	zza 'father'
Three-morae		
Set	Type A	Type B
1	yabizi 'Yabiji coral reef'	yumunu 'mouse'
2	minna 'place name'	hynzya 'goat'
3	kabii 'paper'	ramii 'ramie'
4	zzaku 'oar'	zzara 'sickle'
5	nnagu 'sand'	mmaga 'grandchild'
Four-morae		
Set	Type A	Type B
1	bakamunu 'youngster'	sarahama 'place name'
2	harunna 'snail'	uganda 'Uganda'
3	mazImun 'monster'	doragon 'dragon'

2.1.2 Speaker and recordings

A male native speaker of Ikema Ryukyuan (60 years old) participated in the recordings. Since they were elicited from only one speaker, results should be treated with caution. The speaker read the entire set of test words from six to nine times. The recordings were made using a directional condenser microphone and an Edirol R-09 recorder (16 bits, 44.1 kHz).

2.1.3 Measurements

All the measurements were performed manually in a simultaneous display of the waveform, wide-band spectrogram, and F0 track, using the Praat software [1]. F0 was extracted using the To Pitch command with the pitch floor being 75 Hz and the pitch ceiling being 300 Hz.

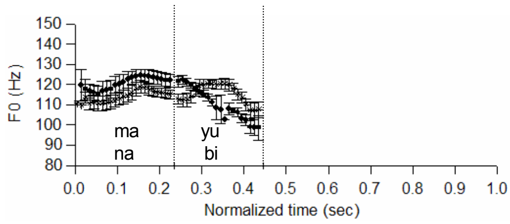
The utterances were all segmented into morae. In addition, we measured the vowel onset of the first mora (*ma* of *mai* or *ka* of *kara-mai*) that follows a PW, so that we could conduct a detailed examination of the F0 movement between the PW and the immediately following particle(s). For the visual inspection of the lexical tone distinction (A vs. B), we generated F0 contours normalized across the repetitions.

2.2 Results

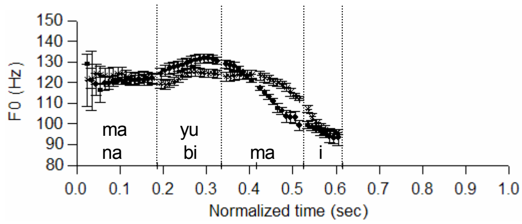
All data were analyzed by means of two-way analyses of variance (ANOVAs), with ACCENT (Type A, Type B) and SET (such as nayu/nabi, mai/bau, in/in, and zzu/zza) as the independent variables.

2.2.1 Two-morae Phonological Words

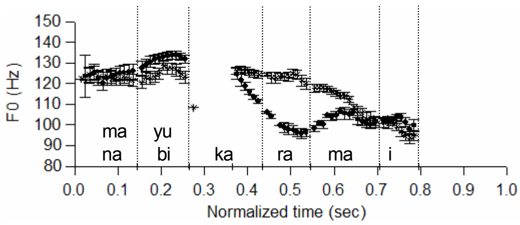
As can be seen from Figure 1 (a), showing the normalized F0 contours for two-mora PWs, *mayu* (A) and *nabi* (B), the lexical tone distinction is realized even in the pronunciation of an isolated word. Specifically, Type A exhibits an F0 fall from the first mora to the second, whereas Type B does not show a considerable fall. We consider the subtle fall observed in Type B PWs to be the result of the phonetic effect of the utterance-final position, i.e. final lowering.



(a) *mayu* vs. *nabi*



(b) *mayu-mai* vs. *nabi-mai*



(c) *mayu-kara-mai* vs. *nabi-kara-mai*

Figure 1 Normalized F0 contours for two-morae PWs, Type A mayu (●) and Type B nabi (x). Error bars indicate SE.

We measured the F0 values in Hz in the middle of the final mora (FINALF0). The means are presented in Table 2. It can be seen that for all the sets, FINALF0 is lower in Type A than in Type B.

Table 2: Mean FINALF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	mayu vs. nabi	110.0 (3.7)	120.3 (6.0)
2	mai vs. bau	102.4 (3.4)	123.3 (2.4)
3	in vs. in	123.3 (10.8)	131.2 (4.4)
4	zzu vs. zza	121.0 (11.3)	123.9 (4.1)

In order to confirm these observations, we conducted a two-way ANOVA with FINALF0 as the dependent variable. The results showed a significant main effect of ACCENT [$F(1,48) = 34.12$, $P < 0.001$]. The results also revealed a significant main effect of SET, [$F(3,48) = 13.08$, $P < 0.001$] and a significant interaction [$F(3,48) = 4.70$, $P < 0.001$]. It was thus revealed that the lexical tone distinction is manifested even when no particles follow the PW. The results are consistent with our previous formulation that the distinction appears at the rightmost position of the word.

Figure 1 (b) shows the F0 contours for two-morae PWs followed by a two-morae particle, *mayu-mai* (A) and *nabi-mai* (B). Confirming our previous descriptions, the difference between Type A and Type B is observed in the height of the particle immediately following the PW: that is, the particle is lower when preceded by a Type A PW than by a Type B PW. Although the difference is clearly perceived, its acoustic salience is masked by a F0 fall that exhibits in the particle following a Type B PW. The fall can, again, be regarded as the result of the final lowering. Nevertheless, the difference between Type A and Type B can be confirmed by acoustic measures. We did this using the following two steps.

First, we measured the F0 value in Hz in the middle of the vowel [a] in the first mora of the particle *mai* (MAIF0). Means are given in Table 3. We can see that in all of the sets, MAIF0 is lower in Type A than in Type B. The results of a two-way ANOVA, with MAIF0 as the dependent variable, showed a significant main effect of ACCENT [$F(1,48) = 84.41$, $P < 0.001$], but no significant main effect of SET, [$F(3,48) = 1.95$, n.s.] and no interaction [$F(3,48) = 1.99$, n.s.].

Table 3: Mean MAIF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	mayu vs. nabi	106.3 (3.8)	118.3 (3.6)
2	mai vs. bau	109.7 (5.3)	118.0 (4.4)
3	in vs. in	107.0 (6.2)	123.3 (4.3)
4	zzu vs. zza	106.6 (5.1)	115.8 (4.3)

Second, we measured the temporal distance in ms between the onset of the vowel [a] in the first mora of the particle *mai* and the F0 peak at the beginning of the fall observed between the PW and the particle (PEAKALIGN). The negative values indicate that the peak precedes the vowel onset. The means are presented in Table 4.

Table 4: Mean PEAKALIGN in ms (SD in parentheses).

	Set	Type A	Type B
1	mayu vs. nabi	-108.0 (14.2)	24.3 (35.0)
2	mai vs. bau	-106.0 (25.3)	-2.5 (4.9)
3	in vs. in	-124.0 (49.1)	16.6 (22.4)
4	zzu vs. zza	-111.0 (8.5)	6.4 (17.2)

It can be seen from the table that the peak is aligned earlier in Type A than in Type B, for all the sets. Again, we ran an ANOVA with PEAKALIGN as the dependent variable. The results showed a significant main effect of ACCENT [$F(1,48) = 340.7$, $P < 0.001$], no significant main effect of SET [$F(3,48) = 0.7$, n.s.], and no interaction [$F(3,48) = 1.4$, n.s.].

Thus, it was confirmed that the particle was low-toned when it was preceded by a Type A word whereas it was high-toned when it is preceded by a Type B word. The difference manifested acoustically as the lower F0 of the particle following the Type A PW and as the earlier peak alignment of the fall in Type A.

Figure 1 (c) depicts the normalized F0 contours for two-morae PWs followed by two two-morae particles, *mayu-kara-mai* (A) and *nabi-kara-mai* (B). Again, the particle immediately following the PW (*kara*) is lower when preceded by the Type A PW than by the Type B PW. It can also be seen from the figure that F0 rises from the first particle *kara* to the second particle *mai* in Type A, whereas it falls in Type B. This is a consequence of the HL alternation.

Table 5 shows the means for KARAF0 defined as the F0 value in Hz in the middle of the vowel [a] in the first mora of the first particle *kara*. We see that in all of the sets, KARAF0 is lower in Type A than in Type B.

Table 5: Mean KARAF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	mayu vs. nabi	99.2 (4.8)	123.3 (5.2)
2	mai vs. bau	99.7 (3.8)	122.9 (4.6)
3	in vs. in	99.5 (6.3)	129.8 (4.5)
4	zzu vs. zza	98.6 (5.1)	126.8 (5.2)

The results of a two-way ANOVA with KARAF0 as the dependent variable showed a significant main effect of ACCENT [$F(1,48) = 386.6$, $P < 0.001$], but no significant main effect of SET, [$F(3,48) = 1.2$, n.s.] and no interaction [$F(3,48) = 1.4$, n.s.].

Then, we examined the difference in F0 between two particles (KARAMAIF0) which was defined as the F0 value of the offset of the vowel [a] in the second particle *mai* minus the F0 value of the offset of the second vowel [a] in the first particle *kara*. The negative values indicate that F0 falls between the first and second particles. The means are presented in Table 6.

Table 6: Mean KARAMAIF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	mayu vs. nabi	4.9 (3.6)	-16.7 (4.3)
2	mai vs. bau	4.3 (2.6)	-17.4 (3.2)
3	in vs. in	3.6 (5.0)	-19.5 (6.2)
4	zzu vs. zza	3.5 (3.0)	-20.45 (6.7)

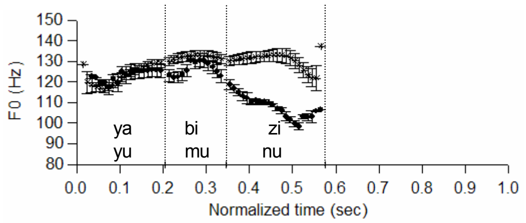
It can be seen from the table that F0 rises in Type A, while it falls in Type B. The results of a two-way ANOVA with KARAMAIF0 as the dependent variable showed a significant main effect of ACCENT [$F(1,48) = 338.1$, $P < 0.001$], but no significant main effect of SET [$F(3,48) = 0.99$, n.s.] and no interaction [$F(3,48) = 0.22$, n.s.].

Thus, the results of the present analyses confirm the HL alternation in Ikema, showing that the first particle was high-toned and the second particle was low-toned in Type B, while the first particle was low-toned and the second particle was high-toned in Type A.

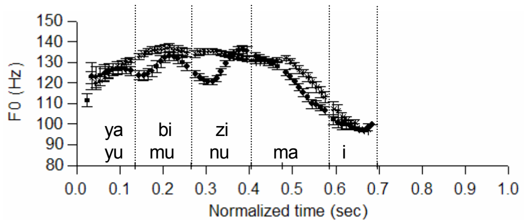
To sum up, the analyses on the two-morae PW confirmed our previous descriptions. First, the distinction appears at the rightmost position of the PW. Type A PWs make the immediately following particle low, while Type B PWs make it high. When there is no particle, the distinction is nevertheless manifested by the presence (Type A) or absence (Type B) of a considerable fall at the end of the PW. Second, the HL alternation is observed when the PW is followed by two two-morae particles. The second particle is high when the first particle is low, while the second particle is low when the first particle is high.

2.2.2 Three-morae Phonological Words

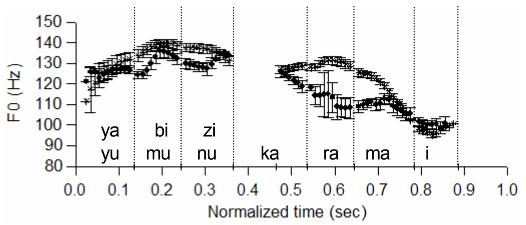
Overall, three-morae PWs showed the same tendency as the two-morae PWs described in 2.2.1. This is not surprising, because both two-morae and three-morae PWs have the identical number of feet (i.e. one), with a high tone linked to the foot.



(a) *yabizi* vs. *yumunu*



(b) *yabizi-mai* vs. *yumunu-mai*



(c) *yabizi-kara-mai* vs. *yumunu-kara-mai*

Figure 2 Normalized F0 contours for three-morae PWs, Type A yabizi (●) and Type B yumunu (x). Error bars indicate SE.

Figure 2 (a) illustrates the normalized F0 contours for three-morae PWs followed by no particles, *yabizi* (A) and *yumunu* (B). We can observe a clear F0 fall at the end of the PW in case of Type A. It can be seen from Table 7 showing the means for FINALF0 (see 2.2.1), that in all of the sets, FINALF0 is lower in Type A than in Type B.

Table 7: Mean FINALF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	yabizi vs. yumunu	107.5 (1.9)	133.0 (6.9)
2	minna vs. hynzya	127.1 (3.4)	141.7 (11.3)
3	kabii vs. ramii	115.7 (3.9)	143.1 (9.5)
4	zzaku vs. zzara	125.3 (14.2)	147.0 (6.4)
5	nnagu vs. mmaga	112.7 (7.8)	126.8 (4.6)

A two-way ANOVA was conducted, with FINALF0 as the dependent variable. The results showed a significant main effect of ACCENT [$F(1,50) = 102.95$, $P < 0.001$]. They also showed a significant main effect of SET, [$F(4,50) = 11.42$, $P < 0.001$] but no interaction [$F(4,50) = 1.8$, n.s.].

Figure 2 (b) shows the normalized F0 contours for three-morae PWs followed by a two-morae particle, *yabizi-mai* (A) and *yumunu-mai* (B). We see from the figure that the lexical tone distinction is manifested in the height of the particle. Just as in the analyses of two-morae PWs, we confirmed this through two acoustic measures, MAIF0 and PEAKALIGN (see 2.2.1).

Table 8, showing the means for MAIF0, confirms that in all of the sets, the particle is lower in Type A than in Type B. The difference was significant according to a two-way ANOVA with MAIF0 as the dependent variable which revealed a significant main effect of ACCENT [$F(1,50) = 93.95$, $P < 0.001$], a significant main effect of SET, [$F(4,50) = 22.70$, $P < 0.001$], and a significant interaction [$F(4,50) = 4.15$, $P < 0.01$].

Table 8: Mean MAIF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	yabizi vs. yumunu	112.9 (4.9)	122.9 (4.7)
2	minna vs. hynzya	120.4 (7.5)	139.0 (6.8)
3	kabii vs. ramii	119.0 (5.2)	147.0 (7.2)
4	zzaku vs. zzara	128.9 (7.6)	146.1 (9.7)
5	nnagu vs. mmaga	113.1 (6.8)	121.8 (1.96)

The means for PEAKALIGN are presented in Table 9, showing an earlier peak alignment in Type A. The results of a two-way ANOVA with PEAKALIGN as the dependent variable revealed a significant main effect of ACCENT [$F(1,50) = 595.01$, $P < 0.001$]. The results also showed a significant main effect of SET [$F(4,50) = 11.15$, $P < 0.001$] and a significant interaction [$F(4,50) = 5.33$, $P < 0.01$].

Table 9: Mean PEAKALIGN in ms (SD in parentheses).

	Set	Type A	Type B
1	yabizi vs. yumunu	-23.5 (6.5)	66.2 (6.9)
2	minna vs. hynzya	-66.0 (18.1)	54.8 (6.3)
3	kabii vs. ramii	-17.5 (6.3)	70.7 (9.3)
4	zzaku vs. zzara	-34.9 (7.0)	74.6 (7.7)
5	nnagu vs. mmaga	-1.7 (39.4)	67.1 (6.7)

Figure 2 (c) depicts the normalized F0 contours for three-morae PWs followed by two two-morae particles, *yabizi-kara-mai* (A) and *yumunu-kara-mai* (B). We see from the figure that the particle immediately following the PW (*kara*) is lower when preceded by a Type A PW than by a Type B PW. Table 10 shows means for KARAF0 (see 2.2.1).

Table 10: Mean KARAF0 in Hz (SD in parentheses).

	Set	Type A	Type B
1	yabizi vs. yumunu	110.0 (10.8)	131.4 (4.5)
2	minna vs. hynzya	115.5 (7.5)	152.3 (9.7)
3	kabii vs. ramii	117.0 (6.6)	151.2 (7.8)
4	zzaku vs. zzara	121.5 (5.3)	149.5 (9.1)
5	nnagu vs. mmaga	103.9 (6.1)	128.8 (4.6)

In all of the sets, KARAF0 is lower in Type A than in Type B. The results of a two-way ANOVA with KARAF0 as the dependent variable showed a significant main effect of ACCENT [$F(1,50) = 222.89$, $P < 0.001$] and a significant main effect of SET [$F(4, 50) = 16.77$, $P < 0.001$], but no interaction [$F(4, 50) = 2.15$, n.s.].

We can also observe the HL alternation from Figure 2 (c), realized as a F0 rise from the first particle to the second in the case of Type A and as a F0 fall from the first particle to the second in the case of Type B. The means for KARAMAIF0 (see 2.2.1) are shown in Table 11.

Table 11: Mean KARAMAIF0 in Hz (SD in parentheses).

Set	Type A	Type B
1 yabizi vs. yumunu	-4.8 (8.0)	-27.3 (3.9)
2 minna vs. hynzya	3.8 (2.1)	-38.4 (10.1)
3 kabii vs. ramii	4.3 (6.5)	-36.6 (8.1)
4 zzaku vs. zzara	1.8 (4.1)	-38.7 (6.4)
5 nnagu vs. mmaga	1.6 (4.9)	-20.5 (10.4)

KARAMAIF0 is positive for all the Type A PWs except Set 1, indicating that F0 rises from the first particle to the second. It can also be seen that in all of the sets, KARAMAIF0 is negative in Type B reflecting an F0 fall. The results of a two-way ANOVA with KARAF0 as the dependent variable showed a significant main effect of ACCENT [$F(1,50) = 356.92$, $P < 0.001$], a significant main effect of SET [$F(4,50) = 3.07$, $P < 0.05$], and a significant interaction [$F(4,50) = 6.84$, $P < 0.001$].

In summary, the results of the analyses on the three-morae PWs were in general the same as those on the two-morae PWs: the lexical tone distinction appeared at the rightmost position of the PW and the HL alternation is observed when the PW is followed by two two-mora particles.

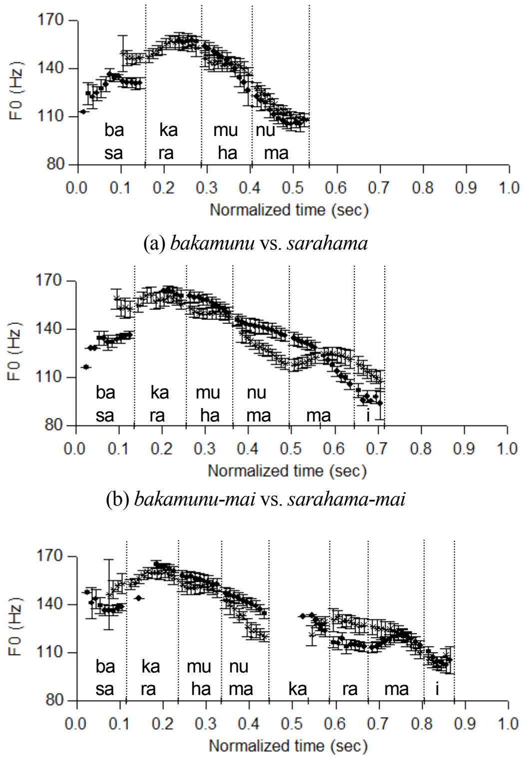


Figure 3 Normalized F0 contours for four-morae PWs, Type A bakamunu (●) and Type B sarahama (x). Error bars indicate SE.

2.2.3 Four-morae Phonological Words

Tone patterning in the four-morae PWs is considerably different from that in the two- or three-morae PWs, because they consist of two feet and thus the non-distinctive lowing related to the HL alternation is observed within the PW. Figure 3 (a) depicts the normalized F0 contours for four-morae PWs followed by no particles, *bakamunu* (A) and *sarahama* (B). We first notice that for both Type A and Type B, there is an F0 fall from the second mora to the third. This is due to the HL alternation.

We also notice that, unlike the case of two- and three-morae PWs, the lexical tone distinction cannot be identified at the end of the PW. Table 12 shows the means for FINALF0 (see 2.2.1). It can be seen from the Table that the difference in the height of the final mora between Type A and Type B is not consistent across the sets. The results of a two-way ANOVA with FINALF0 as the dependent variable showed no significant main effect of ACCENT [$F(1,32) = 1.45$, n.s.], a significant main effect of SET [$F(2,32) = 17.49$, $P < 0.001$], and no interaction [$F(2,32) = 1.95$, n.s.].

Table 12: Mean FINALF0 in Hz (SD in parentheses).

Set	Type A	Type B
1 bakamunu vs. sarahama	97.0 (4.7)	101.4 (3.3)
2 harunna vs. uganda	101.6 (4.5)	98.7 (3.8)
3 mazImun vs. doragon	108.1 (7.4)	112.8 (6.5)

Figure 3 (b) illustrates the normalized F0 contours for four-morae PWs followed by a particle, *bakamun-mai* (A) and *sarahama-mai* (B). We first notice the fall due to the HL alternation. We also notice that the particle *mai* is lower in Type A than Type B. This is confirmed by looking at Table 13, showing the means for MAIF0 (see 2.2.1). The difference in MAIF0 between Type A and Type B was significant according to a two-way ANOVA with MAIF0 as the dependent variable. It was revealed that there was a significant main effect of ACCENT [$F(1,32) = 58.6$, $P < 0.001$], a significant main effect of SET [$F(2,32) = 4.98$, $P < 0.05$], and no interaction [$F(2,32) = 1.80$, n.s.].

Table 13: Mean MAIF0 in Hz (SD in parentheses)

Set	Type A	Type B
1 bakamunu vs. sarahama	100.5 (4.7)	119.4 (5.6)
2 harunna vs. uganda	100.3 (3.4)	121.5 (4.1)
3 mazImun vs. doragon	112.0 (7.3)	123.4 (11.3)

Figure 3 (b) also tells us that the lexical tone distinction also appears around the final mora of the PW. Specifically, the final mora is slightly higher in Type A than in Type B. This sort of difference was not observed for two-morae and three-morae PWs. We consider this to be a phonetic raising effect in Type A PWs, observed before the F0 lowering from the end of the PW to the immediately following particle.

We measured the F0 value of the final mora of the PW (W-FINALF0). The means are presented in Table 14.

Table 14: Mean W-FINALF0 in Hz in the case of –mai. (SD in parentheses).

Set	Type A	Type B
1 bakamunu vs. sarahama	119.4 (5.7)	109.4 (2.8)
2 harunna vs. uganda	118.9 (5.8)	108.4 (5.0)
3 mazImun vs. doragon	140.8 (8.6)	128.9 (8.8)

The results of a two-way ANOVA with KARAF0 as the dependent variable showed a significant main effect of

ACCENT [$F(1,32) = 24.78$, $P < 0.001$] and a significant main effect of SET [$F(2,32) = 43.04$, $P < 0.001$], but no interaction [$F(2,32) = 0.06$, n.s.].

Figure 3 (c) depicts the normalized F0 contours for four-morae PWs followed by two two-morae particles, *bakamunu-kara-mai* (A) and *sarahama-kara-mai* (B). Again, the non-distinctive fall related to the HL alternation can be seen within the PW.

Table 15 shows the means of KARAF0 (see 2.2.1), revealing that the particle is lower in Type A than in Type B in all of the sets. This difference is significant according to a two-way ANOVA with KARAF0 as the dependent variable, which shows a significant main effect of ACCENT [$F(1,32) = 106.74$, $P < 0.001$] and a significant main effect of SET [$F(2,32) = 17.14$, $P < 0.001$], but no interaction [$F(2,32) = 3.24$, n.s.].

Table 15: Mean KARAF0 in Hz (SD in parentheses)

Set		Type A	Type B
1	bakamunu vs. sarahama	99.1 (2.8)	119.9 (5.7)
2	harunna vs. uganda	97.8 (2.5)	123.6 (2.4)
3	mazImun vs. doragon	114.9 (7.4)	128.8 (9.6)

The means for KARAMAIF0 (see 2.2.1) are presented in Table 16. We see that F0 rises between the first and second particles in Type A, whereas it falls in Type B. A two-way ANOVA with KARAF0 as the dependent variable showed a significant main effect of ACCENT [$F(1,32) = 185.72$, $P < 0.001$] and a significant main effect of SET [$F(2,32) = 4.95$, $P < 0.05$], but no interaction [$F(2,32) = 2.26$, n.s.].

Table 16: Mean KARAMAI in Hz (SD in parentheses)

Set		Type A	Type B
1	bakamunu vs. sarahama	1.6 (2.5)	-14.6 (2.5)
2	harunna vs. uganda	6.3 (4.1)	-17.5 (4.1)
3	mazImun vs. doragon	-1.2 (3.3)	-20.0 (5.4)

Just as when followed by a single two-morae particle, the four-morae PWs realize the lexical tone distinction around its final mora. Table 17 presents the means of W-FINALF0. It can be seen again that W-FINALF0 is higher in Type A than in Type B. The difference was significant according to the result of a two-way ANOVA with W-FINALF0 as the dependent variable. It was revealed that there was a significant main effect of ACCENT [$F(1,32) = 34.02$, $P < 0.001$], a significant main effect of SET [$F(2,32) = 22.63$, $P < 0.001$], and no interaction [$F(2,32) = 0.10$, n.s.].

Table 17: Mean W-FINALF0 in Hz in the case of –kara-mai. (SD in parentheses).

Set		Type A	Type B
1	bakamunu vs. sarahama	122.5 (7.9)	109.6 (5.0)
2	harunna vs. uganda	123.7 (6.4)	108.3 (5.5)
3	mazImun vs. doragon	141.2 (8.0)	125.7 (10.7)

In summary, the results generally confirmed our previous descriptions. First, Type A PWs make the immediately following particle low, while Type B PWs make it high. Second, when the PW is followed by two two-morae (one-foot) particles, the HL alternation occurs in the particles: the second particle is high when the first particle is low, while the second particle is low when the first particle is high. These two results were observed in the analyses on the two- and three-morae PWs as well. Third, the HL alternation is observed within the PW, realizing as a word-internal F0 fall.

It was also shown that the lexical tone distinction could not be identified acoustically when the PW was followed by no particles. The results also revealed that, when the PW is followed by one or more particles, the lexical tone distinction appears not only in the particles but also around the final mora of the PW: the final mora was slightly raised in Type A PWs. We see this raising as a phonetic effect that the lowering of a Type A PW induces.

3 Discussion and Conclusion

The results of the present study confirmed our previous descriptions of the tonal system of Ikema Ryukyuan [2]. First, the lexical tone distinction appears at the rightmost position of the PW. Type A PWs make the immediately following particle low, while Type B PWs make it high. When followed by no particles, two- and three-morae (single-foot) PWs realize the distinction with the presence (Type A) or absence (Type B) of a considerable fall at the end of the PW.

Second, a non-distinctive tone patterning called the HL alternation is observed. Four-morae (two-foot) PWs exhibit a fall from H to L, regardless of their lexical tone distinction. The alternation also occurs when the PW is followed by two two-morae (single-foot) particles. The second particle is H when the first particle is L, while the second particle is L when the first particle is H.

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