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PHONETIC IMPLEMENTATIONS OF POHNPEIAN LONG VOWELS*

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This paper examines phonetic properties of long vowels in Pohnpeian, a Micronesian language. A production experiment and a perception experiment were conducted. The results of the production experiment show that Pohnpeian speakers produced long vowels with the mean duration only about 1.5 times longer than that of short vowels. The perception experiment confirmed that the ratio was wide enough for Pohnpeian listeners to discriminate vowel lengths. This study demonstrates a piece of evidence that Pohnpeian speakers acquire the ability to recognize phonological vowel length, one of the phonological features of the language, from their acoustic environment.

1. INTRODUCTION

This paper explores phonetic implementations of Pohnpeian long vowels. "Phonetic implementations," in this paper, refers to the acoustic properties that stimulate speakers' phonological knowledge. Phonological knowledge is the set of perceptual abilities that speakers use to recognize phonological features in their language. Phonological features are language-specific; that is, a certain speech sound in a language is recognized as a meaningful phonological unit only to speakers of the language. For example, click sounds are meaningful speech sounds in many African languages, but they are not in other languages. Likewise, /t/ and /k/ are two contrastive phonemes in many world languages; however, they are not contrastive in Hawaiian. Vowel length, too, is contrastive only in certain languages, such as Finnish, Japanese, and most Austronesian languages. That is, the length of a vowel changes the meaning of a word. For instance, the Pohnpeian words *kang* /kaŋ/ with a short vowel means 'to eat' and the word *kahn* /kaːŋ/ with a long vowel means 'to refuse.' They are a minimal pair contrasting only in vowel length. The vowel length distinction is difficult to detect for a speaker of English, as vowel length distinction is not a feature of English phonology.

As Flemming (2005) states, it is not a new idea that speech perception is involved in developing phonology of speakers. That is, in order to acquire phonological knowledge, speakers must be exposed to a certain acoustic environment and learn which signals are important for their phonological system. In this paper, first, I will compare vowel durations of short vowels and long vowels to find out how Pohnpeian speakers produce the vowel length distinctions. Then, I will also examine if the durational distinction between long and short vowels in production corresponds to the speakers perception of vowel length.

* This paper was not possible without the participants in my experiments. I especially thank Mr. Simion Kihleng for his assistance gathering Pohnpeian speakers and explaining experiment procedures to them. I am also deeply indebt to Amy Schafer for experiment designing. All mistakes are of course mine.

In the following section, I will briefly review phonological characteristics of Pohnpeian vowels by summarizing Rehg and Sohl (1981) and Rehg (1986). Then I will describe a production experiment that I conducted. The section 4 will be about a perception experiment. This paper will end with a brief conclusion.

2. Pohnpeian Vowels

Pohnpeian is a Micronesian language spoken mainly in the Federated States of Micronesia and its surrounding islands. There are seven phonemic vowels, /a, e, ɛ, i, o, ɔ, u/ in the Northern or Main dialect of Pohnpeian,[1] and these vowels are represented by the letters *a*, *e*, *e*, *i*, *o*, *oa*, and *u* respectively. Long vowels are indicated by the letter *h* following a vowel as in (1).

(1) Long vowels		Short vowels	
pah /paː/	'to fight'	*pa* /pa/	'under'
dohl /toːl/	'mountain'	*dol* /tol/	'to mix'

Rehg and Sohl (1981) refer to long vowels as "double vowels," as they might be considered as a sequence of two identical vowels. Based on his investigation on meter of oral literature, Fischer (1959) suggests that in Eastern Carolinian languages, including Pohnpeian, short vowels carry a single mora and long vowels two moras. In other words, long vowels are considered phonologically twice as long as short vowels. Goodman (1995) reports that the duration of long vowels is approximately twice as long as the duration of short vowels based on her acoustic measurements. I however have obtained different results. This might have been due to methodological differences between the two studies. Since the interests of her study are not vowel durations, she does not provide the details of her measurements of vowel durations. I will not regard her result for the present study.

3. Production Experiment

The purpose of this experiment is to examine the durational distinction between long vowels and short vowels in Pohnpeian. Since vowel length is distinctive in Pohnpeian, the duration of long vowels should be significantly longer than that of short vowels, regardless of speech rate. This experiment investigates the way Pohnpeian speakers produce durational distinctions between long vowels and short vowels at various speech rates.

3.1. *Participants*

Four participants, two females and two males, were all fluent bilinguals in English and Pohnpeian. They were living in Honolulu, Hawai'i, but they were all born in Pohnpei and their first language was Pohnpeian. One of each female and male participant was in her/his mid-40s and the other two were in their early 20s. The older participants still had distinct Pohnpeian accents in their English, although both of them had been educated in English when they were in

[1] In the Kitti dialect, another major dialect in Pohnpeian, the vowels /e/ and /ɛ/ are not contrastive. Consequently, they have only six phonemic vowels.

Pohnpei and spoke English fluently. The younger participants were students at the University of Hawai‘i at Mānoa, and they did not speak English with a Pohnpeian accent. This might have been because of the bilingual education system developed in Pohnpei over the last several decades (Rehg 1998). The younger generations of Pohnpeian were more likely to have been exposed to a bilingual environment since they were children.

3.2. *Material*

The material used in this experiment was 20 minimal/near minimal pairs contrasting vowel length such as *kang* /kaŋ/ ‘to eat’ vs. *kahng* /kaːŋ/ ‘to refuse’ and *lul* /lul/ ‘to flame’ vs. *uluhl* /uluːl/ ‘pillow’ (see Appendix A for the complete list). The target words were uttered in a carrier sentence *Ia wehwehn* ______ *ni lokaiahn Pohnpei* /ja wɛːwɛːn _____ ni lokajaːn poːnpej/ ‘What is the meaning of _____ in Pohnpeian?’ Each sentence was read at three different speech rates – fast, normal, and slow, in order to examine if the speakers distinguish vowel length differently in fast speech from slow speech. Asking them to read the sentence at three different speech rates should make it easier for the speakers to differentiate fast speech from slow speech.

3.3. *Procedure*

The sentence containing the target word was written on an index card in standard Pohnpeian orthography. The desired speech rate was indicated at the upper left-hand corner of each card. The fast speech rate was described as ‘As fast as you can’, the normal speech rate ‘At the normal speed’, and the slow speech rate was ‘As if you are speaking to an elderly person’. The material sentences were presented in a way that the participants would not repeat the same sentence consecutively at a different speech rate. The participants were asked to read without pausing within a sentence, as a pause would change intonation patterns that might affect the duration of target word and/or vowel.

All recordings were made in a sound-attenuated studio. The utterances were tape-recorded on a TANDBERG TCR522 cassette-recorder through a 3M tabletop microphone and digitized with Pitchworks at a sampling rate of 22,050 Hz. For formant readings, *Praat* (Boersma & Weenink 2002) was used.

I measured vowel durations and pitch movements. The duration of vowels was determined by the existence of F2 and F3. In addition, I measured the duration of the whole target word and sentence to assure that participant utter the sentences at the desired speech rate. Pitch movement was measured to examine if there was any indication of pitch movement associated with vowel length as was observed in Japanese vowels (Kozasa Forthcoming). The amount of pitch movement was measured from the highest F0 point in the target vowel to the lowest F0 point in the following syllable nucleus.

3.4. *Results*

I must report two phenomena that I did not expect to observe. First, none of speakers was able to make a distinction between fast speech rate and normal speech rate or between slow speech rate and normal speech rate in all sentences. In other words, each speaker uttered some sentences with shorter duration at normal speech rate than that at fast speech rate, or with longer duration at normal speech rate than that at slow speech rate. However, the duration of sentences in fast speech was always shorter than that in slow speech in all speakers' data. Thus, I used the data only from the two extreme speech rates; that is, fast speech and slow speech.

Second, none of speakers read all target vowels as they were written. For example, the vowels in the minimal pair *pehi* 'alter' vs. *pei* 'to float' were both pronounced [peːj], with a long vowel, and the vowels in the minimal pair *neh* 'leg' vs. *ne* 'to be distributed' were both pronounced [neː], also with a long vowel. Several reasons could account for this misproduction of vowel length. One possibility is that the speakers were not paying careful attention to the written form of the target words. Since the speakers were not used to participating in an experiment, they might have felt strange producing Pohnpeian words in a semantically neutral sentence. Consequently, they altered the target word to a more suitable form in the carrier sentence, which is the noun form, rather than as it was written, which is the verb form. Most Pohnpeian verbs occur with suffixes in a natural utterance. For example, the word *pei* 'to float' occurs with a directional suffix *-do* as in *peido* 'to float here' Therefore, it is possible that the speakers produced the noun form *neh* for both *neh* 'leg' and *ne* 'to be distributed'. Likewise, they chose the more familiar form *luhs* for both *luhs* 'to lose' and *lus* 'to jump.' Therefore, I closely examined each speaker's data. I summarized the mean durations of each phonemic vowel produced by each participant in Table 1. The numbers in boldface indicate the cases in which the mean duration of long vowels was shorter than that of short vowels. I also created a figure for each speaker's data to show the mean durations of each vowel varied within a speaker (see Appendix B).

Table 1. Mean durations of vowels by each speaker in production experiment (adopted from Kozasa 2005, p.129)

Speaker	F-1		F-2		M-1		M-2	
Fast	Short (ms)	Long (ms)	Short (ms)	Long (ms)	Short (ms)	Long (ms)	Short (ms)	Long (ms)
/a/	137.33	160.05	112.28	170.85	85.68	136.35	102.05	192.05
/ɛ/	188.60	279.40	**215.00**	**170.60**	79.60	122.10	196.20	207.50
/e/	141.50	145.10	**94.60**	**55.90**	59.61	98.80	76.90	109.10
/i/	**140.35**	**131.00**	96.00	122.56	63.93	112.84	123.05	153.24
/o/	139.90	158.00	128.40	162.95	77.20	136.68	71.47	180.17
/ɔ/	178.70	188.70	131.30	167.88	95.38	151.68	119.38	170.15
/u/	**144.77**	**125.57**	96.58	110.08	84.97	104.30	79.07	156.70
Slow	Short (ms)	Long (ms)	Short (ms)	Long (ms)	Short (ms)	Long (ms)	Short (ms)	Long (ms)
/a/	187.03	251.38	149.85	229.88	112.63	191.60	102.80	262.73
/ɛ/	221.90	296.40	236.30	237.60	98.80	180.70	220.50	295.10
/e/	**157.40**	**128.90**	**136.20**	**122.10**	128.40	156.50	156.00	171.70
/i/	232.03	252.83	127.73	156.42	82.08	157.52	121.63	246.82
/o/	179.37	267.70	145.13	199.98	88.23	198.58	91.77	211.23
/ɔ/	256.93	296.78	211.20	232.30	138.76	173.83	125.90	210.65
/u/	140.50	214.57	134.10	175.08	86.57	155.60	95.87	206.98

Note: F-1 = 1st female speaker, F-2 = 2nd female speaker, M-1 = 1st male speaker, M-2 = 2nd male speaker

The variability was more obvious in the female speakers than in male speakers. This might be because the Pohnpeian males are more careful about their speech, since they have more opportunities to speak formally in public than the Pohnpeian females. Since the mean durations of the vowel /ɛ/ deviated the most throughout the speakers, except for speaker M-1, the analysis was done without measurements of this vowel.

I performed repeated measures 2-way ANOVAs to examine the effect of vowel length (long vs. short) and speech rate (fast vs. slow) on the mean duration of vowels. Table 2 shows the results treating speakers as a sample of the population, and Table 3 results treating vowel types (the six Pohnpeian vowels) as a sample of the population.

Table 2. Analysis by speakers: Mean durations of vowels and ratios (adopted from Kozasa 2005, p.131)

	Long vowel (ms)	Short vowel (ms)	Ratio (Long : Short)
Fast speech	150.129	115.210	1.30 : 1.00
Slow speech	213.149	145.469	1.47 : 1.00
Ratio (Fast : Slow)	1 : 1.41	1 : 1.27	

Table 3. Analysis by vowel types: Mean durations of vowels and ratios (adopted from Kozasa 2005, p.131)

	Long vowel (ms)	Short vowel (ms)	Ratio (Long : Short)
Fast speech	142.599	108.033	1.32: 1.00
Slow speech	199.224	137.771	1.45: 1.00
Ratio (Fast : Slow)	1 : 1.40	1 : 1.28	

The results show that the mean duration of long vowels was significantly longer than short vowels ([F(1,3) = 13.444, *p* = .0351] by speakers and [F(1,5) = 27.440, *p* = .0034] by vowel types). In addition, speech rate had a significant effect on the duration of vowels ([F(1,3) = 26.192, *p* = .0144] by speakers and [F(1,5) = 126.617, *p* < .0001] by vowel types), which suggests that the mean duration of vowels became longer in slow speech than that in fast speech. However, there was no significant interaction between the two independent variables (speech rate and vowel length) by speakers ([F(1,3) = 7.681, *p* = .0695], Figure 1).[2] This interaction pattern between the two independent variables suggests that Pohnpeian speakers maintained similar proportional distinctions between the mean duration of long vowels and short vowels, regardless of speech rate.

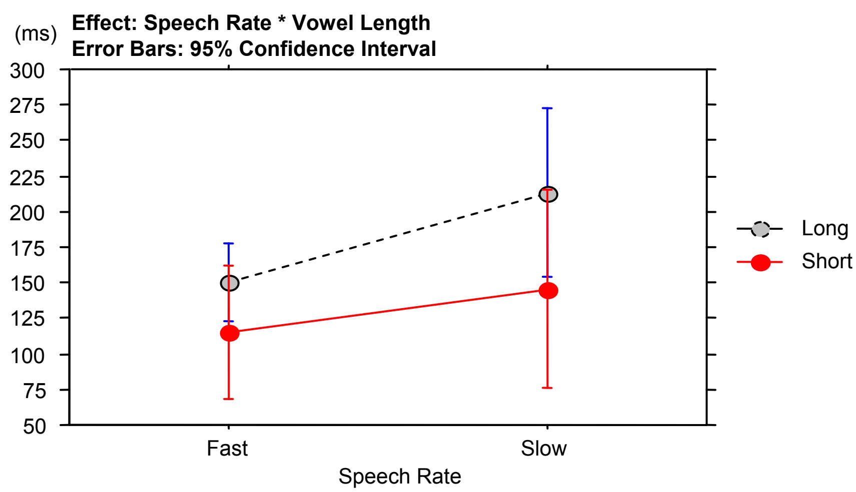


Figure 1. Interaction line plot in production experiment

The mean amount of pitch movement was not significantly different between long vowels and short vowels. The table below shows pitch fall in Pohnpeian vowels. I performed repeated measures 2-way ANOVAs to examine the mean amount of pitch movement in vowels. There was no significant effect of speech rate ([F(1,3) = .022, *p* = .8820] by speakers and [F(1,5) = .488, *p* = .4854] by vowel types) nor vowel length ([F(1,3) = .003, *p* = .9564] by speakers and [F(1,5) = .616, *p* = .4332] by vowel types) on the amount of pitch movement. This result suggests that F0 (pitch movement) did not play any role in Pohnpeian vowel length distinctions.

[2] The interaction between the two independent variables by vowel types was significant ([F(1,5) = 8.660, *p* = .0322], which might have been an influence of the differences in intrinsic duration of each vowel.

Table 4. Analysis by speakers: Mean pitch falls and ratios in production experiment (adopted from Kozasa 2005, p.134)

	Long vowel (Hz)	Short vowel (Hz)	Ratio (Long : Short)
Fast Speech	23.611	25.120	1.00 : 1.06
Slow Speech	23.840	24.216	1.00 : 1.02
Ratio (Fast : Slow)	1.00 : .1.01	1.04 : 1.00	

3.5. *Discussion*

The results of the production experiment show that the mean duration of long vowels was only 1.30 to 1.47 times longer than that of short vowels. These ratios are rather small compared to other languages in which vowel length is distinctive. For example, it is reported that the ratio of the duration of long vowels to short vowels is 2.27 : 1.00 in Finnish, 1.98 :1.00 in Danish, 2.20 : 1.00 in Estonian (Lehiste 1970) and 2.4-3.2 : 1.0 in Japanese (Hirata 2004). Furthermore, the ratio of the mean duration of long vowels to short vowels was maintained throughout different speech rates in Pohnpeian. It seemed that Pohnpeian speakers used another supplemental acoustic cue to indicate vowel length. Since F0 movement had nothing to do with vowel length distinction, it is natural to wonder if Pohnpeian speakers used spectral differences to mark vowel length. Although vowel length is not distinctive, the difference in vowel duration is clearly audible between tense vowels and lax vowels in English. For example, the duration of the English tense vowel /i/ in a word such as *beat* is longer than the lax vowel /ɪ/ in *bit*.

To examine vowel quality, I must consider vowel allophony in Pohnpeian. In Pohnpeian, the realization of vowel quality varies according to adjacent consonants.[3] When a front vowel, such as /i/, is surrounded by front consonants,[4] it stays as [i], such as in the word *pil* [pil] 'water.' Both consonants /p/ and /l/ are front consonants, surrounded the front vowel /i/. However, when the vowel is in the back environment, such as in the word *tip* /t ip/, the vowel realizes as [ɨ], since it is preceded by a back consonant /t /. Likewise, a back vowel, such as /u/, realizes as [u] in a back environment such as in *pwupw* [p^wup^w]; and when the vowel is in a front environment, it changes to [ʉ] as in *lul* [lʉl] 'to flame.' According to Rehg and Sohl (1981), the variation of the quality in long vowels is not as noticeable as short vowels. Therefore, there is a possibility that Pohnpeian speakers use spectral cues to indicate vowel length. I examined vowel quality in the data; however, I did not observe quality differences between long and short vowels, except in the data from the older male participant. This particular participant was able to produce 19 out of 20 target minimal pairs correctly. Since this experiment was not intended to examine the quality differences in long vowels and short vowels, I must wait for further investigations to draw a strong conclusion; nonetheless, it seems that this male participant was using spectral differences as well as durational differences to indicate vowel length distinctions.

[3] Similar phenomenon is observed in Marshallese (Bender 1968), and Choi (1992) confirms it with his acoustic analyses.

[4] Pohnpeian consonants are divided into front and back depending on their point of articulation. The consonants /p, t, m, n, s, l, w/ are categorized as front and /p^w, k, m^w, ŋ, t , r, j/ are back consonants (Rehg and Sohl 1981).

Although I observed some instances of spectral differences between long vowels and short vowels, there are still significant durational differences between the mean duration of long vowels and the mean duration of short vowels. The question is how much they are different. In other words, how long does vowel duration need to be for Pohnpeian listeners to perceive a vowel as long? Does the duration correspond to the results of the production experiment? I will investigate these questions in the following section.

4. PERCEPTION EXPERIMENT

The results of the production experiment show that the mean duration of long vowels was significantly longer than that of short vowels. However, the mean duration of long vowels was less than 1.5 times of the mean duration of short vowels. Furthermore, this ratio did not change significantly at various speech rates. Does this mean that Pohnpeian listeners do not require wide durational difference between long vowels and short vowels? Are they sensitive to durational differences in vowels? How do they categorize vowel length? In order to investigate the way Pohnpeian listeners use durational cues to categorize vowel length, I conducted an ABX discrimination test.

4.1. *Participants*

There were 26 participants in this perception experiment. They were all native speakers of Pohnpeian who lived in Honolulu or Hilo, Hawaiʻi. The age ranged from the early 20s to the late 50s. Seven of them were students at the University of Hawaiʻi at Mānoa or Hilo campus. These students were fluent bilingual speakers in Pohnpeian and English. Although they were students, they were interacting with other Pohnpeian speakers in a community by attending church or casual weekly gatherings. The other participants were residence in Honolulu, Hawaiʻi. They were educated in English in Pohnpei and living in the United State, but they were using Pohnpeian in their daily life, as they lived and/or worked with other Pohnpeian speakers.

4.2. *Stimuli*

I chose a three-syllable sound sequence (CVCVCV) as the form of stimuli, setting a target vowel in the middle of the sequence. The duration of the first and the last vowels in the stimulus could function as a standard for listeners to identify the length of the target vowel. Considering the vowel allophony in Pohnpeian, I chose a front vowel /e/ and a front consonant /p/. Either *epepe* or *epehpe* was nonsense word in Pohnpeian; consequently, the stimuli did not contain any lexical information. The categorization of vowel length should be determined purely by durational cues.

A female native speaker of Pohnpeian produced an utterance *epepepepepe*. The speaker was asked to recite the material without pitch movement and at a comfortable speech rate for her. The recorded speech sample was digitized with Pitchworks at a sampling rate of 22,050 Hz. The original stimulus *epepe* was extracted from the middle of the digitized speech sample. The original duration of the second vowel was lengthened to 130, 140, 150, 154, 156, 160, 166, 170, 180,[5] and 200 % with SoundEdit. The actual durations of these target vowels are shown in Table 5. The duration of the first vowel of the stimuli was 84.7 ms and the last vowel 86.6 ms.

Table 5. The duration of target vowels

Target vowels	
Stimulus	Duration (ms)
100	85.0
130	108.8
140	119.8
150	127.6
154	130.2
156	135.0
160	138.0
166	140.9
170	146.2
180	154.2
200	170.1

4.3. *Procedure*

In the ABX test, the stimuli were arranged in triads. Each triad consisted of an A stimulus, a B stimulus, and an X stimulus in this order. Listeners heard each triad one at a time through headsets and decided if the third stimulus X was similar to the first stimulus (the A stimulus) or the second (the B stimulus). When the A stimulus was the original stimulus, the B stimulus was the manipulated stimulus whose target vowel was lengthened to 200 % of the original one. When the A stimulus was the manipulated stimulus whose target vowel was lengthened to 200% of the original one, the B stimulus was the original stimulus. The X stimuli were the ones with a target vowel of ambiguous duration; that is, the stimuli with a medial vowel lengthened to 130, 140, 150, 154, 156, 160, 166, 170, and 180 % of the original length. The A and B stimuli were also used as the X stimuli to detect the accuracy of each participant's performance. There was a 700 ms pause between the A stimulus and the B stimulus and between the B stimulus and the X stimulus. There was a 1000 ms pause between the participant's response (pressing a button) and the following A stimulus. This procedure is schematized in Figure 2.

There were six blocks of triads. Each block consisted of the same set of triads, but the triads were arranged in the different order. In order to move on to the next block, listeners were asked to press a button, which allowed them to take a short break between blocks. There were four practice triads prior to the real experiment session. In the practice triads, the X stimuli were either identical to the A stimulus or the B stimulus.

[5] Since I used SoundEdit to manipulate vowel durations, they came out with uneven increment.

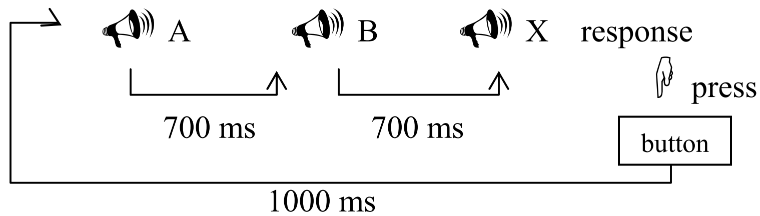


Figure 2. Sequence of an ABX trial

The experiment was conducted in a quiet room – a sound attenuated booth, a conference-room on campus, or a room in a participant's home. The procedure was explained orally in English to the student participants and in Pohnpeian to non-student participants. An instruction written in English was also displayed on the computer screen before the practice session. After the practice session, participants were asked whether they understood the task, and if it was necessary, the practice session was repeated.

4.4. *Results*

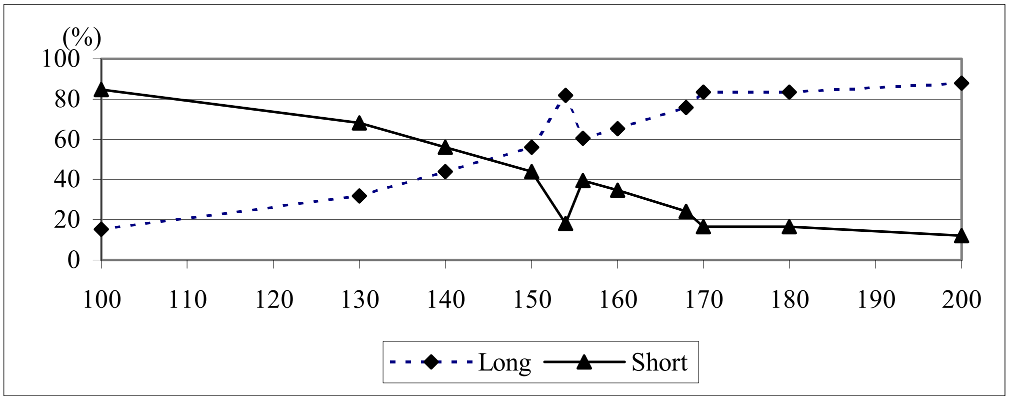
First, I assessed the accuracy of listeners' responses. It was possible, since there were the triads in each six blocks that the X stimulus was identical to the A stimulus or the B stimulus. If a listener missed more than 20 % of these triads, the data from the listener were not used for the analyses. I was able to use the data from 11 listeners whose accuracy was better than 80%.

Stimulus	Responses	
	Long (%)	Short (%)
100	15.15	84.85
130	31.82	68.18
140	43.94	56.06
150	56.06	43.94
154	81.82	18.18
156	60.61	69.39
160	65.15	34.85
166	75.76	24.24
170	83.33	16.67
180	83.33	16.67
200	87.88	12.12

Table 6. Mean responses to the X stimuli

Then I calculated the average of the listeners' responses for each X stimulus. Table 6 shows the percentages that listeners categorized the ambiguous stimuli as long or short. Pohnpeian listeners categorized vowels as long more than a half of the time (56.06 %), even when the duration was only 150 % longer than the original short vowel. Figure 3 shows the crossover point of the listeners' vowel length categorization. The dotted line indicates the responses as long and the solid line as short. It was earlier than the 150 % stimulus.

Figure 3. Mean responses to the X stimuli[6]



I conducted a chi-square (χ^2) test for responses to each stimulus to examine if categorizations were made randomly. The results are in Table 7. The results suggest that the listeners started to be confused about vowel length when the duration of target vowel was 130 % longer than the short vowel and that they were able to determine the length of the target vowels when they were 180 % longer than the short vowel.

Stimulus	χ^2	*p*
100	**19.667**	**.033**
130	10.667	.384
140	8.000	.629
150	9.333	.501
154	17.000	.074
156	10.333	.412
160	11.333	.332
166	**18.333**	**.050**
170	18.000	.055
180	**19.333**	**.036**
200	**21.667**	**.017**

Table 7. Results of χ^2 test

[6] Since there was no target vowel lengthened to 110, 120, and 190 % of the original vowel, there are no values for those stimuli in the figure.

4.5. *Discussion*

The purpose of conducting this ABX discrimination test was to investigate how Pohnpeian speakers respond to durational cues for vowel length. The results show that although long vowels are phonologically considered to bear two units (two moras), in order for Pohnpeian speakers to perceive a vowel as long, they did not require the duration to be twice as long as short vowels. They seemed to identify vowel length as long when the duration was more than 150 % or more of the duration of short vowels. They required the duration to be longer than 180 % of short vowels to determine vowel length as long confidently, yet when the duration was longer than 130 % of the duration of short vowels, the listeners could not recognize a vowel as short any more. The results from the production experiment show that Pohnpeian speakers produced the mean duration of long vowels as only 1.3 to 1.5 times longer than that of short vowels. Pohnpeian long vowels are phonologically considered to be twice as long as short vowels, but phonetically the mean duration of vowels is not necessarily twice as long as short vowels for both production and perception. Furthermore, the ratio of the mean duration of long vowels to short vowels seems to correspond with the categorical threshold of vowel length.

5. Conclusion

Phonology is language-specific, and so is phonetics. It is a well-accepted fact that acoustic properties of voiceless stops such as a /p/ in Spanish are different from those in English, even though they are recognized as the same phoneme in each language and are represented by the same phonemic symbol /p/. Likewise, the ratio of the mean duration of long vowels to short vowels is different among languages which distinguish vowel length from long to short, as I have mentioned in Section 3.5. These acoustic differences could facilitate developing different phonological knowledge.

Phonetic implementations should be reflected listeners' perception of phonemic features. However, as Fowler and Galantucci (2005) point out that speech production and speech perception have been investigated separately. Kozasa (2005) shows that durational properties of Japanese long vowels correspond with the listeners' categorization patterns of vowel length. I this paper, I have also shown that the phonetic properties of long vowels in Pohnpeian agree with the patterns of listeners' perception of vowel length.

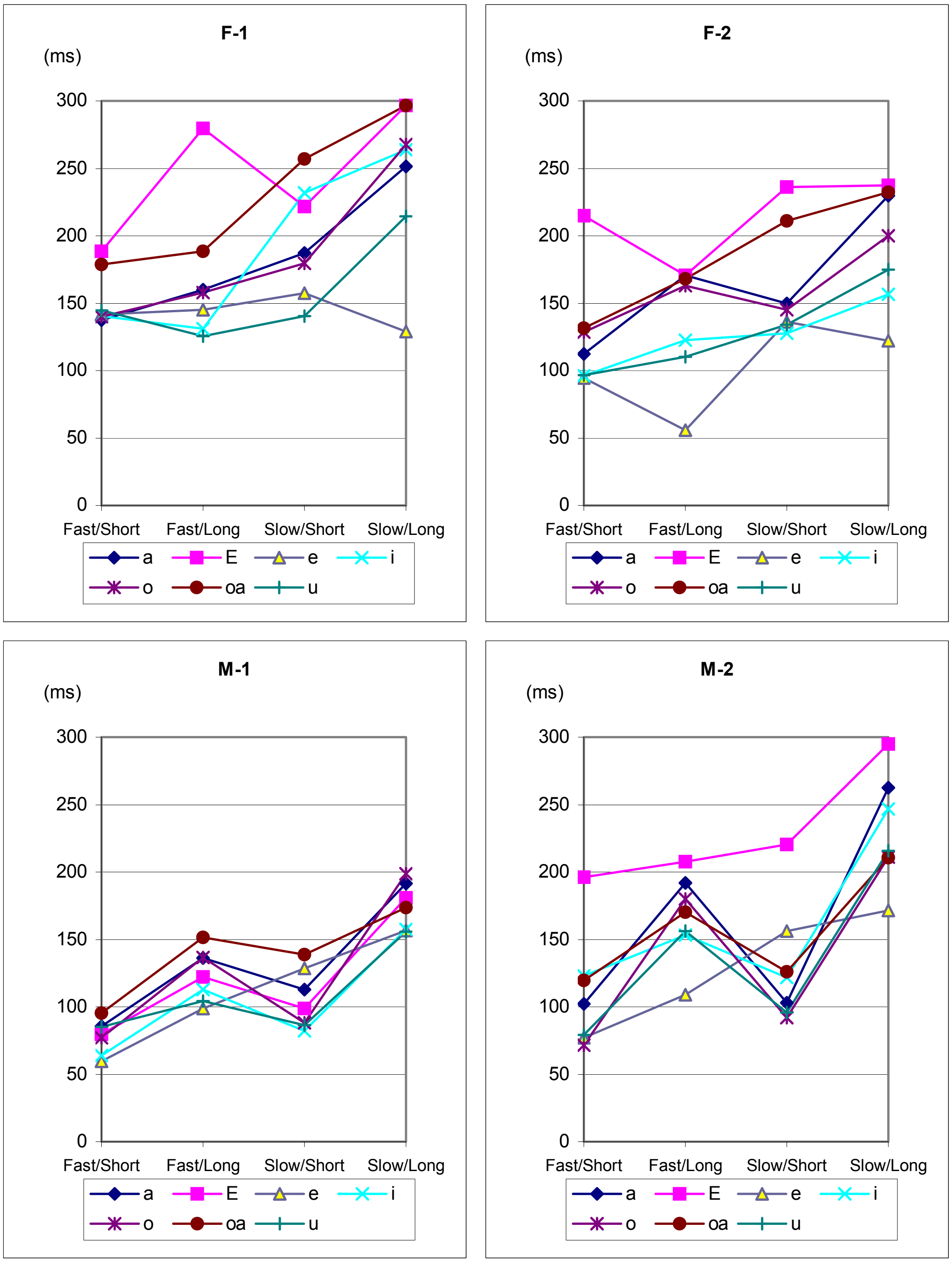
The findings of these studies support the claim that our phonological knowledge is emerged or learned only by being exposed to a speech environment. In order to understand how speakers develop phonological knowledge internally, it is important to examine phonetic implementations of phonological features.

Appendix A. Material words used for production experiment

Carrier sentence: *Ia wehwehn ______ ni lokaiahn Pohnpei*
/ja wɛːwɛːn _____ ni lokajaːn poːnpej/
'What is the meaning of _____ in Pohnpeian?'

	Long vowel			**Short vowel**	
/aː/	*kahng* /kaːŋ/	‘to refuse’	/a/	*kang* /kaŋ/	‘to eat’
	mahs /maːs/	‘long ago’		*aramas* /aramas/	‘person’
	pahpa /paːpa/	‘father’		*pap* /pap/	‘to swim’
	sahl /saːl/	‘rope’		*lal* /lal/	‘to make a sound’
/eː/	*pehi* /peːj/	‘alter’	/e/	*pei* /pej/	‘to fight’
/ɛː/	*neh* /nɛː/	‘its leg’	/ɛ/	*ne* /nɛ/	‘to be distributed’
/iː/	*ihd* /iːt/	‘plant (sp.)’	/i/	*id* /it/	‘to make a fire’
	kihd /kiːt/	‘garbage’		*kid* /kit/	‘thousand’
	lih /liː/	‘woman’		*lil* /lil/	‘to lower a sail’
	pihl /piːl/	‘water’		*pil* /pil/	‘also’
/oː/	*dohl* /toːl/	‘mountain’	/o/	*dol* /tol/	‘to mix’
	kohri /koːri/	‘ice’		*korila* /korila/	‘gorilla’
	tohto /t̪oːt̪o/	‘many’		*litok* /lit̪ok/	‘hen’
/ɔː/	*poahd* /pɔːt/	‘individual planting	/ɔ/	*poad* /pɔt/	‘to be planted’
	poahr /pɔːr/	‘to wipe’		*poar* /pɔr/	(classifier)
	soahn /sɔːn/	‘wounded’		*soan* /sɔn/	‘aligned’
	poahsoan /pɔːsɔn/	‘foundation’		*poasen* (*kaung*) /pɔsɛn kau̯ŋ/	
/uː/	*luhs* /luːs/	‘to lose’	/u/	*lus* /lus/	‘to jump’
	pwuhng /p^{w}uːŋ/	‘rights’		*pwung* /p^{w}uŋ/	‘correct’
	uluhl /uluːl/	‘pillow’		*lul* /lul/	‘to flame’

Appendix B. Scatter plots of mean durations of vowels in production experiment (adopted from Kozasa 2005, p.130)



Note: a = /a/, E = /ɛ/, e = /e/, i = /i/, o = /o/, oa = /ɔ/, u = /u/

References

Bender, Byron W. 1968. Marshallese phonology. *Oceanic Linguistics*, VII.16-35.

Boersma, Paul and D Weenink. 2002. *PRAAT.* from http://www.fon.hum.uva.nl/praat/.

Choi, John D. 1992. *Phonetic underspecification and target-interpolation: An acoustic study of Marshallese vowel allophony*, PhD thesis, Los Angeles: UCLA.

Fischer, Jack L. 1959. Meter in Eastern Carolinian oral literature. *Journal of American Folklore*, 72.47-52.

Flemming, Edward. 2005. Speech perception and phonological contrast. In David B. Pisoni and Robert E. Remez (eds.) *The handbook of speech perception*, pp. 156-81. Malden, MA: Blackwell.

Fowler, Carol A. and Bruno Balantucci. 2005. The relation of speech perception and speech production. In David B. Pisoni and Robert E. Remez (eds.) *The handbook of speech perception*, pp. 633-52. Malden, MA: Blackwell.

Goodman, Beverley D. 1995. *Features in Ponapean phonology*. PhD thesis, Ithaca: Cornell University.

Kozasa, Tomoko. 2005. *An acoustic and perceptual investigation of long vowels in Japanese and Pohnpeian*. PhD thesis, Honolulu: University of Hawai‘i at Mānoa.

Kozasa, Tomoko. Forthcoming. The interaction of duration and pitch in Japanese long vowels. *Proceedings of the 30th Annual Meeting of the Berkeley Linguistics Society*.

Rehg, Kenneth L. 1986. *The phonology of Ponapean vowels*. PhD thesis, Honolulu: University of Hawai‘i at Mānoa.

Rehg, Kenneth L. 1998. Note from the field: Taking the pulse of Pohnpeian. *Oceanic Linguistics*, 37.323-45.

Rehg, Kenneth L. and Damian G. Sohl. 1981. *Ponapean reference grammar*: PALI Language Texts: Micronesia. Honolulu, HI: University of Hawaii Press.