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海陸腔客語母音的聲學研究

An Acoustic Study of Hai-lu Hakka Vowels

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An Acoustic Study of Hai-lu Hakka Vowels

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Chinese Abstract

國立政治大學語言學研究所碩士論文提要

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本論文為以共振峰頻率資料來研究海陸腔客語母音音質之聲學研究。

語言學的文獻中，以共振峰頻率資料來研究世界上各種語言的母音的音質已經有相當豐富的文獻，在過去五十年來，前人在客語的語音及音韻系統上已經有豐富的研究成果。但以聲學資料來對海陸客語做描述的文獻相當缺乏。

本研究的受試者為居住在新竹縣新埔鎮，六位以海陸腔客家話為母語的人士，其中有三名男性及三名女性。本研究使用了 32 個測試字，包含了單元音、雙合元音及三合元音。語音資料是利用 KAY CSL 4100 (KAY Electronics)來做分析。本研究測試字包含的音節結構有:CV, CVV, CVVC, CVC, 以及 CVVV。測試字在實驗的過程中，被受試者單獨發音，或是放在句子中間。在實驗資料完成分析後，我們以 Origin 6.0 軟體繪出海陸腔客語母音的聲學空間圖。

根據供振峰研究資料，本研究得到以下有關海陸腔客語母音音質的表現。首先關於單元音，海陸腔客語共有六個單元音: [i], [e], [ɨ], [a], [o], 以及 [u]。其次，海陸腔客語共有十一個雙元音:[ie], [ia], [io], [iu], [eu], [ai], [au], [oi], [ui], [ue], 以及 [ua]。我們比較單元音及雙元音的聲學空間圖(vowel space)後，發現相同的母音在雙母音的環境下，由於受到鄰近母音發音位置的影響，在聲學空間上，比起在單母音的時候，變的更高低，或更前或後。第三，三母音[iai], [iau]和[uai]在聲譜圖上的表現，第一個母音[i]和[u]都比其後的兩個母音，長度來的相對的短一些，表現很像是滑音[j]和[w]。

最後，本研究以共振峰聲學頻率的形式描述及記錄了當代海陸腔客語母音的音質，前人的研究中，以楊時逢(1952)最能說明本研究所提供的聲學資料。希望這些資料能對海陸腔客語母音的研究有所貢獻。

關鍵詞：海陸腔客語；聲學空間圖；母音音質；聲學語音學；共振峰頻率

Abstract

This thesis is an acoustic study that investigates the vowel quality of Hai-lu Hakka vowels with formant frequency data.

The acoustic method has been widely applied to the study of vowel quality of languages worldwide. In the past 50 years, Hakka researchers have yielded rich results in phonological system and phonetic description of Hakka, but there are relatively fewer research focus on the acoustic properties and characteristics of vowel phones in Hai-lu Hakka.

The subjects of this study included three male and three female native Hai-lu Hakka speakers. Testing items used in this study were 32 syllables that involve monophthongs, diphthongs, and triphthongs. The speech data were analyzed by using KAY CSL 4100 (KAY Electronics). The data discussed in this study were testing items produced in citation form and sentence form, including the following syllable structures: CV, CVC, CVV, CVVC, and CVVV. The vowel qualities of Hai-lu Hakka vowels were measured and analyzed, and the acoustic vowel space of Hai-lu Hakka is plotted by the software Origin 6.0.

Several results concerning the vowel quality of Hai-lu Hakka vowels were reported based on the formant frequency data. Firstly, there are six monophthongs in the vowel system of Hailu Hakka: [i], [e], [ɨ], [a], [o], and [u]. Secondly, there are eleven diphthongs in the vowel system of Hai-lu Hakka : [ie], [ia], [io], [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua]. By comparing the relative position of the vowel in a diphthong and the corresponding vowel as in a monophthong, we found that the second vowel in a diphthong tend to be higher or lower, more fontal or back, and it is possibly due to the coarticulatory influence of the adjacent phones.the Thirdly, as shown in the spectrogram of the three tripthongs [iai], [iau] and [uai], the duration of [i] in [iai55], [i] in [t^hiau55] and [u] in [kuai55] are relatively shorter than the rest two vowels in the same syllable, as [ai] in [iai55], [au] in [t^hiau55] and [ai] in [kuai55]. In these CVVV syllables, [u] and [i] are similar to glides or so-called semi-vowels, or approximants [j] and [w] as shown in the spectrogram.

Finally, the vowel system in Yang (1957) is more suitable for accounting for the data in this study. Hopefully, the vowel formant data presented in this study will contribute to the study of vowels in Hakka.

Keywords: Hai-lu Hakka; vowel space; vowel quality; acoustic phonetics;
formant frequency

CHAPTER I

INTRODUCTION

1.0 Introduction

This thesis attempts to investigate the vowel quality of Hai-lu vowels from an acoustic investigation. Under this study, the dialect spoken in Hsinchu County of Taiwan will mainly be explored. The focus of this paper attempts to investigate the phonetic properties of all vowel phones of Hai-lu Hakka's phonetic system.

The acoustic method has been widely applied to the study of vowel quality of languages worldwide. Ladefoged and Maddieson (1996) employed the acoustic method in the sound of the world's languages. Other surveys of vowels by acoustic approach in the world's language, includes Danish, (Fischer-Jorgensen, 1972); Dutch, (Pols, Tromp & Plomp, 1973), American English (Peterson & Barney, 1952; Olive, Greenwood & Coleman, 1993; Hillenbrand, Getty, Clark & Wheeler, 1995; Ladefoged, 2006), British English (Wells, 1963), Japanese (Chiba & Kajiyama, 1941), Korean (Yang, 1992; Yuen, 2001), Russian (Halle, 1959) Swedish (Fant, 1973), Beiging Mandarin (Howie, 1976; Wu 1986, Zee 2000, 2001; Zee & Lee 2001), Cantonese (Zee, 1999),Taiwanese Southern Min (Myers & Tsay 2003), Taiwan Mandarin (Liu, Zeng & Cao, 1999; Fon, Chiang & Chueng, 2004; Pan, Li, Lee, Huang & Tsou, 200), and Hakka (Liang, 2004; Huang, 2004; Deng, 2006; Zee & Lee, 2008; Zee & Lee, 2009).

Traditionally, in research of vowels in world's languages, vowels are usually described with the tongue position (relative height and backness) and the roundness of lips as an articulatory aspect. However, some subtle differences in vowel quality are hard to capture with the conventional classification. Besides conventional analysis, the method of acoustic analysis provides researchers with an objective and precise way to describe the quality of vowels. With the help of modern acoustic analysis apparatus and by converting the physical attributes of vowels into concrete digital numbers, acoustic analysis is an objective and precise way to describe the quality of vowels. The experimental results can reveal more concrete realities of Hakka vowel phones based on scientific analyses.

This chapter is organized as follows. Section 1.1 introduces the Hakka language. Section 1.2 reviews previous phonological studies on Hakka vowels, including Si-xian Hakka and Hai-lu Hakka. Section 1.3 presents the purpose of this thesis. Research questions are shown in section 1.4.

1.1 Hakka Language

Hakka, one of the major Chinese subdivisions or varieties and is spoken natively by the Hakka people in southern China and the island of Taiwan and throughout the diaspora areas of East Asia, Southeast Asia and around the world. Hakka is not mutually intelligible with Mandarin, Wu, Minnan, or other branches of Chinese. It is most closely related to Gan, and is sometimes classified as a variety of Gan. Because of its original usage in scattered isolated regions where communication is limited to the local area, the Hakka language has developed different variants or dialects. The Hakka language has numerous variants or dialects, spoken in Guangdong, Fujian, Jiangxi, Guangxi, Sichuan, Hunan, Guizhou, including Hainan and Taiwan.

In Taiwan, Hakka is the third largest speech group. The sub-dialects of Hakka in Taiwan can be classified into two main systems: Si-xian Hakka and Hai-lu Hakka. In this study, we mainly focus on the Hai-lu Hakka only spoken by native speakers living in the Hsinchu area. Hai-lu Hakka is mainly spoken in northern Taiwan, in particular, Hsinchu County.

1.2 Hakka Studies

In the past 50 years, Hakka researchers have yielded rich results in phonological system and phonetic description of dialects of Hakka, but there are relatively less research focus on the acoustic properties and characteristics of vowel phones in Hai-lu Hakka.

In accounting for the phonological system of Hakka, autosegmantal phonology and Optimality Theory are adopted in Hakka linguistic research (Hsiao, 1991, 1994; Chung, 1992, 1994, 1995). Among previous linguistic studies on Hakka spoken in

Taiwan, most of them have focused on Si-xian dialects of Hakka. Other varieties of dialects, such as Hai-lu (Chen 2001), Chao-an (Chen, 2000), Rao-ping (Hsu, 2002, 2005), Yong-ding (Lee, 2003), Chong-lok, Da-pu, have received relatively less attention from researchers.

Some attempts have so far been made at Hakka phonetic and phonological studies with acoustic or experimental approaches (Liang, 2004; Huang, 2004; Deng, 2006; Cheng et al., 2009; Zee & Lee, 2008, 2011). Liang (2004) conducted acoustic research to describe the acoustic properties of consonants and vowels of Si-xian Hakka in his thesis. Huang (2004) investigated the physical realities of the Hakka tones and vowels by taking acoustic and statistical approaches. Cheng et al. (2009) explored the systematicity and variability of the vowel pattern in Sixian Hakka from an acoustic perspective. Zee & Lee (2008) conducted studies on the effect of vowel duration on formant frequencies, and analysis of tone and tone sandhi in Hakka dialect, both based on the acoustic data from Hakka spoken in Mainland China. Zee & Lee (2011) conducted acoustic studies on the Yongding Hakka vowels.

In the past 50 years, Hakka researchers have yielded rich results in phonological, syntax, morphological and semantic studies in dialects of Hakka, but there are relatively less research focuses on the acoustic properties and characteristics of vowel phones in Hai-lu Hakka. Therefore, the purpose of the present study is to fill the research gap.

1.3 Purpose of the Thesis

The purpose of this thesis aims to discover the acoustic characteristics of Hai-lu Hakka vowels. Many of the features required for linguistic descriptions of vowels have been established for some time. In research of vowels in world's languages, vowels are usually described with the tongue position (relative height and backness) and the roundness of lips as an articulatory aspect (Bell, 1867; Sweet, 1877; Jones, 1956). However, some subtle differences in vowel quality are hard to capture with the conventional classification. Besides conventional analysis, the method of acoustic analysis provides researchers with an objective and precise way to describe the quality of vowels. From an acoustic phonetic point of view, Steven and House (1955) and Fant (1960) point out that the most important articulatory characteristics of vowels are the point of maximum constriction of the vocal tract. With the help of modern acoustic analysis apparatus and by converting the physical attributes of vowels into concrete digital numbers, acoustic analysis is an objective and precise way to describe the quality of vowels.

The introduction to the acoustic method on vowel quality is provided in Ladefoged's (1971, 1995, 1996, 2000, 2006) series of introductory books to phonetics. The concept of vowel quality includes two main features: height and backness that contrast one vowel with another and four other minor features such as rhotacization, rounding, advanced tongue root, and nasalization (Ladefoged, 2006). The acoustic feature of vowel quality is mainly represented by the frequencies of the first two formants, the first formant (F1) and the second formant (F2). Generally, the first formant frequency decreases when the height of the vowel goes up and the second formant frequency decreases when the backness of the vowel moves backward.

Since conventional Hakka phonological studies cannot provide a precise and objective way to describe and analyze Hai-lu Hakka vowels, we adopt the method of acoustic analysis to describe the quality of vowels. This study is a phonetic analysis of the single vowels, diphthongs and triphthongs in Hai-lu Hakka. We hope that the formant frequency data provide a basis for the transcription of the Hai-lu Hakka vowel system.

1.4 Research Questions

This study aims to investigate the nature of Hakka vowels by acoustic analysis. We try to answer the following research questions:

(1) How many single vowels in Hai-lu Hakka are there under study? A vowel sound whose quality doesn't change over the duration of the vowel is called a monophthong. Monophthongs are sometimes called "pure" or "stable" vowels. All languages have monophthongs and many languages have diphthongs, but

triphthongs or vowel sounds with even more target qualities are relatively rare cross-linguistically. Nearly all languages have at least three phonemic vowels, usually /i/, /a/, /u/ , and very few languages have fewer, though some have been argued to have just two, /ə/ and /a/. With the acoustic data, we aim to discover how many monophthongs are there in Hai-lu Hakka under study.

(2) How many diphthongs in Hai-lu Hakka are there under study? Diphthongs are types of vowels where two vowel sounds are connected in a continuous, gliding motion. They are often referred to as gliding vowels. Most languages have a number of diphthongs, although that number varies widely, from only one or two to fifteen or more. With the acoustic data, we aim to discover how many diphthongs there are in Hai-lu Hakka under study.

(3) What are the three vowels represented in the spectrogram? In phonetics, a triphthong is a monosyllabic vowel combination involving a quick but smooth movement of the articulator from one vowel quality to another that passes over a third. A spectrogram is a time-varying spectral representation (forming an image) that shows how the spectral density of a signal varies with time. Also known as spectral waterfalls, sonograms, voiceprints, or voicegrams, spectrograms are used to identify phonetic sounds, to analyze the cries of animals or many other

fields. With the acoustic data, we aim to discover what the three vowels are represented in the spectrogram.

(4) What position should each Hai-lu Hakka vowel be located in a vowel space? Peter Ladefoged (1993) recommended use of plots of F1 against F2 – F1 to represent vowel quality. In the fourth edition of his book (Ladefoged, 2001), he changed to adopt a simple plot of F1 against F2, and this simple plot of F1 against F2 was maintained for the fifth (and final) edition of the book (Ladefoged, 2006). Hayward (2000) compares the two types of plots, and she concludes that plotting of F1 against F2 – F1 "is not very satisfactory because of its effect on the placing of the central vowels", so she also recommends using a simple plot of F1 against F2. As a matter of fact, this kind of plot of F1 against F2 has been used by analysts to show the quality of the vowels in a wide range of languages. In this study, we adopt the simple plot of F1 against F2 as plotting the vowel space of Hai-lu Hakka.

For these objectives to be achieved, the thesis is structured as follows. Chapter two reviews the literature that is relevant to the topic of this thesis. Chapter three focuses on the methods adopted in the present study, including the details of the subjects in section 3.1. The design of the test words and equipments used in the study are shown in section 3.2. Procedures of the experiment and the acoustic measurement are presented in section 3.3.

Chapter four presents the findings and discussion of the results of the study. Section 4.1 provides overview of the data. Section 4.2 presents the detailed data and spectrogram of monophthongs, Section 4.3 gives the detailed data and spectrogram of diphthongs, and the detailed data and spectrogram of triphthongs are shown in 4.4. Section 4.5 is the summary of the findings. Concluding remarks are shown in chapter five.

CHAPTER II

LITERATURE REVIEW

This review of literature focuses on the previous studies that are related to the topic of thesis. This review includes the literature on the history of transcription of vowel system, the phonological system of Hakka, three studies of Hai-lu Hakka vowels, and acoustic studies on Hakka.

This chapter is divided into five main sections. Section 2.0 gives an introduction to the transcription of vowel. In section 2.1, we give a brief summary of the phonological system of Hakka, including consonants, vowels, and tone. Section 2.2 provides an introduction to the phonological research on the Hai-lu Hakka vowels conducted by three researchers (Yang, 1992; Lo, 1990; Chen, 2000). The discussion on the three studies is provided in 2.3.

In section 2.4, an introduction is offered for the acoustic theory and approach. The acoustic theory and approach have been widely applied to linguistic studies of speech sounds cross-linguistically.

In section 2.5, acoustic phonetic studies on dialects of Hakka spoken in Taiwan and Mainland China will be introduced. Acoustic research on dialects of Hakka, including Liang (2004), Huang (2004), Cheng et al. (2009), and Zee & Lee (2008, 2011) will be summarized. Summary of this chapter and motivation of this thesis are included in section 2.6.

2.0 Introduction to vowel transcription

Description of phonetics is concerned with the physical properties of speech sounds or signs (phones): their physiological production, acoustic properties, auditory perception, and neurophysiological status. On the other hand, phonology concerns itself with systems of phonemes, abstract cognitive units of speech sound or sign which distinguish the words of a language. A phoneme is the smallest contrastive unit in the sound system of a language. A phone is one of many possible sounds in the languages of the world. Phones that belong to the same phoneme, such as [t] and [tʰ] for English /t/, are called allophones.

Many authors agree that vowel transcription is more difficult than consonant transcription (Ball, 1991, 1993; Butcher, 1989; Howard & Heselwood, 2002b). Vowel identification is more difficult and problematic than consonant identification (Cutler, Smits, & Cooper, 2005). Due to the constraints on perception imposed by individual phonology (Best & Tyler, 2007), there is greater difficulty with transcription of vowels than with that of consonants (Ball, 1991, 1993; Butcher, 1989; Howard & Heselwood, 2002b).

The phonetic transcription of vowel sounds is based on the International Phonetic Alphabet (IPA) cardinal vowels. Cardinal vowels refer to a system of auditory and articulatory standard reference points whose symbols embody information about the fundamental vowel parameters of height, fronting and rounding. The IPA system provides the tools for describing a speaker's vowel system without reference to accent or language, and it is valuable in its ease of interpretation by anyone trained in its use (Howard & Heselwood, 2002b). Phonetic transcription is the ideal form for establishing the characteristics of a speaker's productions.

The IPA provides the framework for transcribing vowels, and each individual transcript should be interpreted in the context of speech patterns of the community. One way to represent such community patterns is through a standard phonemic description of the dialect, and the other way is to examine the detailed phonetic transcriptions of speech with reference to this phonemic foundation. Either way, they should satisfy the requirement of representation but must also be based on the principles of the IPA which require symbols to be selected that best describe the articulatory and auditory quality of the speakers.

Acoustic analyses of speech data can empirically provide objective information about the speech signal. The interpretation of vowel acoustic analyses often relies on the correlations between the first two vocal tract resonant frequencies and the articulatory parameters as vowel height and fronting. Figure 1.1 illustrates the traditional vowel map with major IPA cardinal vowel positions indicated. The traditional vowel map is plotted by the values of formant 1 (F1) and formant 2 (F2) plotted on a graph with appropriately oriented and scaled axes.

Figure 1.1 Acoustic vowel space

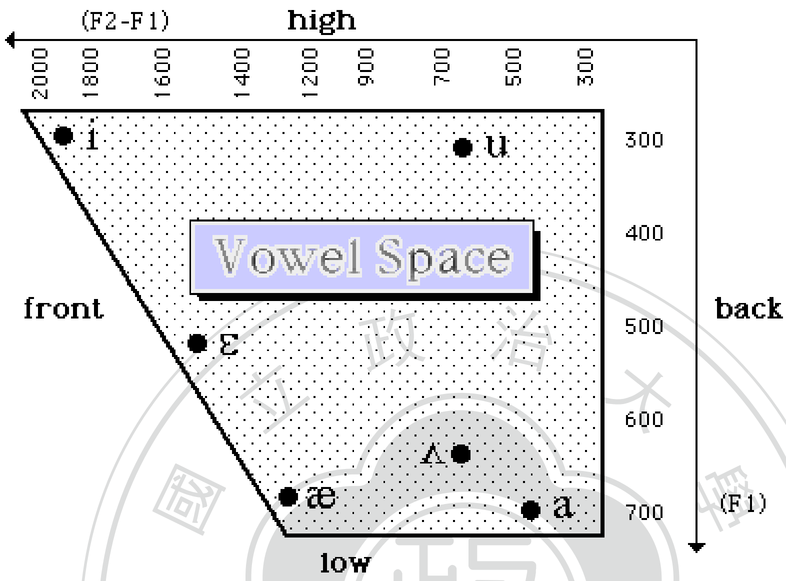


Figure 1.1 is an acoustic vowel space showing how monophthongs can be objectively represented in the F1/F2 plane. With this graphical representation of acoustic data, we can provide objective foundation for comparing the relationships between vowel productions in actual spoken language and the abstract IPA cardinal vowel positions.

2.1 Hakka Phonological System

This section describes the phonological system of Hai-lu Hakka, including syllable structure, consonants and vowels of Hakka.

2.1.1 Hakka Syllable Structure

As one of Chinese languages, Hakka shares the same model of syllable structure with most Chinese dialects. The structure contains four components: Initial, Medial, Nucleus and Ending. Initial refers to the first consonant (except the glides [j] and [w]) in a syllable. Medial is the prevocalic glides. Nucleus is always a vowel or sometimes a syllabic nasal. Ending of a syllable in Hakka refers to nasals [m, n, ŋ], stops [p, t, k], or glides [j] and [w] (Chung, 2004). The rhyme is comprised by medial, nucleus and ending. There are at least sixteen possible syllable shapes, V, VC, VG, VN, GV, GVG, GVC, GVN, CV, CGV, CVC, CVN, CVG, CGVG, CGVN, CGVC, where G is a glide and N a nasal (Chung, 2004).

2.1.2 Hakka Consonants

In Si-xian Hakka, there are 18 consonants. There are 22 consonants in Hai-lu Hakka, by adding two palatal fricatives [ʃ] and [ʒ], and two alveolo-palatal affricates [tʃ] and [$tʃ^h$]. Table 1.1 shows the 22 consonants in Hai-lu Hakka.

Table 1.1 The 22 consonants of Hai-lu Hakka

	Bilabial	Labio-dental	Alveolar	Alveolo-palatal	Palatal	Velar	Glottal
Plosive	p p^h		t t^h			k k^h	
Fricative		f v			ʃ ʒ		h ɦ
Affricate			ts ts^h	tʃ $tʃ^h$			
Nasal	m		n			ŋ	
Lateral			l				
Glide	w				j		

2.1.3 Hakka Vowels

The six single vowels in Hakka sound system are [i], [e], [ɨ], [a], [o], and [u]. The high central unrounded vowel [ɨ] occurs only after the dentals [ts-], [ts^h-], [s-] and the alveolo-palatals [tʃ-], [tʃ^h-], and [ʃ-], for example, [sɨ] 字‘word’ (Chung, 2004). Table 1.2 lists the six vowels of Hai-lu Hakka.

Table 1.2 The six vowels of Hai-lu Hakka

	Front	Central	Back
High	i	ɨ	u
Mid	e		o
Low		a	

2.1.4 Hakka Tone System

The tone system of Hai-lu Hakka is introduced in this section. The description of tone system of Hakka follows the convention of tone letters of Chao (1930). The tone letter system of Chao (1930) divides the pitch into five levels, with the lowest being assigned the value 1, and the highest the value 5.

The tone system of Si-xian and Hailu Hakka is given in Table 1.3.

Table 1.3 The tone system of Si-xian and Hai-lu Hakka

Si-xian	Hai-lu
Tone value	
33	53
11	55
31	13
55	31
	33
3	3
5	5

Hakka preserves all of the entering tones of Middle Chinese. In Hakka literature, an entering tone, or a checked tone, is not a tone in the phonetic sense, but rather describes a syllable that ends in a stop consonant, such as stops [p, t, k].

2.2 Literature on the Studies of Hai-lu Hakka Vowels

Over the past few years, some studies have been made on the phonological system of Hakka. In the following sections, three phonological studies of Hai-lu Hakka vowels are summarized and compared. Among the three authors, there are several different hypotheses concerning the surface and underlying form of Hai-lu Hakka vowels. Yang (1992), Lo (1990) and Chen (2000) will be introduced in following sub-sections.

2.2.1 The vowel system of Yang (1957)

In the book of Yang (1957) *The Hakka Dialect of Tao-yuan, Taiwan*, Yang introduces the phonological system and vocabulary of Si-xian and Hai-lu Hakka spoken in Tao-yuan area, Taiwan. His observation and investigation come from his field study in Tao-yaun area in 1957. The vowel system of Hai-lu Hakka from Yang's work will be summarized in the following sub-sections.

2.2.1.1 Underlying Vowels

The underlying vowels in the phonological system of Hai-lu Hakka proposed by Yang (1957) are presented in Table 1.4. The six vowels in Hakka sound system are /i/, /e/, /ɨ/, /u/, /o/, and /a/.

Table 1.4 Underlying vowels in Hai-lu Hakka (Yang, 1957)

	Front	Central	Back
High	i	ɨ	u
Mid	e		o
Low		a	

2.2.1.2 Surface Vowels

According to Yang (1957), the surface vowels in Hai-lu Hakka are listed in Table 1.5. The ten diphthongs include [ie, ia, io, iu, eu, ua, ai, au, oi, ui] and the three triphthongs include [iai, iau, uai].

Table 1.5 Surface vowels in Hai-lu Hakka of studies (Yang, 1957)

Monophthong	i e ɨ a o u
Diphthong	ie ia io iu eu ua ai au oi ui
Triphthong	iai iau uai

2.2.1.2.1 High Vowels /i/, /ɨ/, and /u/

According to Yang, high vowels are pronounced differently in various environments. The high front vowel /i/ is pronounced as the lower [ɪ] as a single vowel, and the tongue position of /i/ is close to the place between [i] and [e]. In diphtohongs, it is also pronounced as a lower variant [ɪ]. Compared with the other Hakka dialect mainly spoken in Taiwan area -- Si-xian Hakka, the vowel [i] is pronounced much closer to the cardinal vowel [i].

The high central unrounded vowel /ɨ/ has two surface variants, [ɿ] and [ʒ]. When /ɨ/ is after the dentals /ts-/, /ts^h-/, /s-/, the vowel is [ɿ]. When /ɨ/ is after the alveolo-palatals /tʃ-/, /tʃ^h-/, /ʃ-/, it becomes the fricative [ʒ].

The high back rounded vowel /u/ has two surface variants: [ʊ] and [u]. The tongue position of [ʊ] is between the high rounded vowel [u] and the mid back rounded vowel [o] as in the following types of rhyme structure combination: [iu], [eu], [au], [ui], [uŋ], [ut], [uk], [iau], [iuŋ], [iut], and [iuk]. The 60 possible combinations of rhyme structure of Hai-lu Hakka from Yang (1957) is provided in section 2.2.1.3. According to Yang (1957), the tongue position of [u] is near the cardinal vowel [u] in the following types of rhyme structure: [un] and [iun].

2.2.1.2.2 Mid Vowels /e/ and /o/

Similar to high vowels, Yang thought Hakka mid vowels have surface variants in different environments.

The mid front unrounded vowel /e/ has two variants: [e] and [ę]. The tongue position of the vowel is close to that of a cardinal vowel [e] as in the following rhyme structures: [eu] and [en]. It is a lowered front mid vowel [ę] in the following types of combination: [ie], [em], [ep], [et], [iet] and [uet].

As for the mid back rounded vowel /o/, there are two variants: [ɔ] and [ǫ]. [ɔ] appears as in the following types of rhyme structure: [oi], [on], [ion], [oŋ], and [ioŋ]. The tongue position of [ǫ] is lower than [o] but higher than [ɔ], and it appears as in the following types of rhyme structure: [io], [ok], and [iok]. On the other hand, in Si-xian Hakka, /o/ is always pronounced as a sound [ǫ] between [o]and [ɔ].

2.2.1.2.3 Low Vowel /a/

Similar to high vowels and mid vowels, Yang thought Hakka low vowel has surface variants in different types of combination.

The low central vowel /a/ has four allophones: [a], [ä], [ẹ], and [ɑ]. The tongue position of the vowel is near the cardinal vowel [a] as in the following two types of rhyme structure: [an] and [uan]. [ä] is a more centralized vowel, and this variant appears as in the following types of rhyme structure: [ia], [ua], [ai], [iai], [uai], [am], [iam], [ap], [iap], [at], [uat], [ak], and [iak]. The vowel [ẹ] is lower than [e] and [ɛ], and it appears as in [ian]. In rhyme structures [aŋ], [iaŋ], and [uaŋ], the position of the tongue is close to the cardinal vowel [ɑ]

2.2.1.3 Rhyme Structure

As mentioned in 2.1.1, the syllable structure of Hai-lu Hakka shares the same model of syllable structure with most Chinese dialects. The structure contains four components: Initial, Medial, Nucleus and Ending. Initial refers to the first consonant (except the glides [j] and [w]) in a syllable. Medial is the prevocalic glides. Nucleus is always a vowel or sometimes a syllabic nasal. Ending of a syllable in Hakka refers to nasals [m, n, ŋ], stops [p, t, k], or glides [j] and [w] (Chung, 2004). The rhyme is comprised by medial, nucleus and ending. There are at least sixteen possible syllable shapes, V, VC, VG, VN, GV, GVG, GVC, GVN, CV, CGV, CVC, CVN, CVG, CGVG, CGVN, CGVC, where G is a glide and N a nasal (Chung, 2004).

Yang (1957) lists 60 types of possible rhyme structures in Hai-lu Hakka as listed in Table 1.6. As for Si-xian Hakka, Yang lists 61 possible rhyme structures by adding [ieu]. The possible rhyme types of Hai-lu Hakka are listed in Table 1.6.

Table 1.6 rhyme structures in Hai-lu Hakka (Yang ,1957)

CV	CVV/CVC	CVVV/CVVC
i	ie	iai
e	ia	iau
ɨ	io	iam
a	iu	ian
o	im	iaŋ
u	in	iap
	ip	iak
	it	ion
	eu	ioŋ
	em	iun
	en	iuŋ
	ep	iet
	et	iut
	ɨp	iok
	ɨt	iuk
	ai	uai
	au	uan
	am	uaŋ
	an	uat
	aŋ	uet
	ap	
	at	
	ak	
	oi	
	on	
	oŋ	
	ot	
	ok	
	ui	
	ua	
	un	
	uŋ	
	ut	
	uk	

2.2.2 The Vowel System of Lo (1990)

Lo (1990) proposed different phonetic and phonological description of Hakka spoken in Hsinchu County. The vowel system of Hai-lu Hakka in Lo's study will be summarized in the following.

2.2.2.1 Underlying Vowels

According to Lo (1990), the underlying vowels in Hai-lu Hakka are listed in Table 1.7. The six vowels in Hakka sound system are /i/, /e/, /ɨ/, /u/, /o/, and /a/.

Table 1.7 Underlying vowels in Hai-lu Hakka (Lo, 1990)

	Front	Central	Back
High	i	ɨ	u
Mid	e		o
Low		a	

2.2.2.2 Surface Vowels

According to Lo (1990), the surface vowels in Hai-lu Hakka are listed in Table 1.8. The eight diphthongs include [ie, ia, io, iu, eu, au, ua, ue] and the four triphthongs include [iai, iau, ioi, uai].

Table 1.8 Surface vowels in Hai-lu Hakka (Lo, 1990)

Monophthong	i e ɨ a u o
Diphthong	ie ia io iu eu au ua ue
Triphthong	iai iau ioi uai

Lo's (1990) generalization and analysis on Hakka phonological system and phonetic properties are summarized as follows. Concerning the high front unrounded vowel /i/, the rhyme structure combinations /ien/ and /iet/ are in complementary distribution with /iam, iaŋ/ and /iap, iak/. In Hai-lu Hakka, the actual pronunciations of /ien/ and /iet/ are [ian] and [iat]. The rhyme combination /iai/ is rare that it only occurs in colloquial conversation, thus there is no corresponding word for this vowel.

The high central unrounded vowel /ɨ/ has two variants: [ɿ] and [ə]. The alveolar apical [ɿ] occurs after the dentals /ts-/, /tsʰ-/, /s-/, and the schwa [ə] occurs in [əm, ən, əp, ət]. They are in complementary distribution.

Concerning the high back rounded vowel /u/, four kinds of rhyme structure combination, [uat], [uet], [uot], and [uok], are disappearing gradually. For example, the word [kuet] (meaning, *country*) is pronounced [ket] in Si-xian Hakka.

2.2.2.3 Rhyme structure

As mentioned in 2.1.1, the syllable structure of Hai-lu Hakka shares the same model of syllable structure with most Chinese dialects. The structure contains four components: Initial, Medial, Nucleus and Ending. Initial refers to the first consonant (except the glides [j] and [w]) in a syllable. Medial is the prevocalic glides. Nucleus is always a vowel or sometimes a syllabic nasal. Ending of a syllable in Hakka refers to nasals [m, n, ŋ], stops [p, t, k], or glides [j] and [w] (Chung, 2004). The rhyme is comprised by medial, nucleus and ending. There are at least sixteen possible syllable shapes, V, VC, VG, VN, GV, GVG, GVC, GVN, CV, CGV, CVC, CVN, CVG, CGVG, CGVN, CGVC, where G is a glide and N a nasal (Chung, 2004).

According to the analysis in Lo (1990), there are 63 types of rhymes in Hai-lu

Hakka. The possible rhyme types are listed in Table 1.9.

Table 1.9 Rhyme structures in Hai-lu Hakka (Lo ,1990)

CV	CVV/CVC	CVVV/CVVC	Syllabic nasal
i	ie	ien	m̩
e	ia	iet	n̩
ɨ	io	iau	ŋ̩
a	iu	iam	
o	im	iaŋ	
u	in	iap	
	ip	iak	
	it	ion	
	eu	ioŋ	
	em	iok	
	en	iun	
	ep	iuŋ	
	et	iut	
	ɨp	iuk	
	ɨt	uen	
	ɨm	uet	
	ɨn	uan	
	au	uaŋ	
	am	uat	
	an		
	aŋ		
	ap		
	at		
	ak		
	on		
	oŋ		
	ot		
	ok		
	ue		
	ua		
	un		
	uŋ		
	ut		

	uk		

2.2.3 The vowel system of Chen (2000)

Chen (2000) provides a description of phonological system and lexicon of Hai-lu Hakka in his field work in Zhudong, Hsinchu County. His observation of vowels of Hai-lu Hakka will be introduced in the following sub-sections.

2.2.3.1 Underlying vowels

The six underlying vowels of Hai-lu Hakka in Chen (2000) are presented in Table 1.10. The six vowels are /i/, /e/, /ɨ/, /u/, /o/, and /a/.

Table 1.10 Underlying vowels in Hai-lu Hakka (Chen, 2000)

	Front	Central	Back
High	i	ɨ	u
Mid	e		o
Low		a	

2.2.3.2 Surface Vowels

According to Chen (2000), the surface vowels in Hai-lu Hakka are listed in Table 1.11. The nine diphthongs include [ie, io, iu, eu, ai, au, oi, ui, ue, ua] and the three triphthongs include [iau, ioi, uai].

Table 1.11 Surface vowels in Hai-lu Hakka (Chen, 2000)

Monophthong	i e ɨ a u o
Diphthong	ie io iu eu ai au oi ui ue ua
Triphthong	iau ioi uai

As for the Hai-lu Hakka vowels, Chen makes the following observation. When the single high vowels [i] and [u] occur as the last segment in the word, they are pronounced with higher tongue position. The high central unrounded vowel /ɨ/ occurs only after the dentals /ts-/, /tsʰ-/, /s-/ and the alveolo-palatals /tʃ-/, /tʃʰ-/, and /ʃ-/.

Regarding the combination of diphthongs, the mid vowel [-e] only goes with the high back vowel [-u] as in [eu] and [ue]. The mid back vowel [-o] only goes with [-i], as in [io] and [oi].

2.2.3.3 Rhyme structure

As mentioned in 2.1.1, the syllable structure of Hai-lu Hakka shares the same model of syllable structure with most Chinese dialects. The structure contains four components: Initial, Medial, Nucleus and Ending. Initial refers to the first consonant (except the glides [j] and [w]) in a syllable. Medial is the prevocalic glides. Nucleus is always a vowel or sometimes a syllabic nasal. Ending of a syllable in Hakka refers to nasals [m, n, ŋ], stops [p, t, k], or glides [j] and [w] (Chung, 2004). The rhyme is comprised by medial, nucleus and ending. There are at least sixteen possible syllable shapes, V, VC, VG, VN, GV, GVG, GVC, GVN, CV, CGV, CVC, CVN, CVG, CGVG, CGVN, CGVC, where G is a glide and N a nasal (Chung, 2004).

In Chen's (2000) observation and instigation of Hai-lu Hakka spoken in Jhudong, Hsinchu County, there are 59 types of rhyme structure, as listed in Table 1.12. In Chen's observation, some rhyme combinations have few examples in Hakka vocabulary, such as [-ioi], [-iot], [-ep], [-uen], [-uat], [-uak], and [-uaŋ]. These rhyme combinations have only one or two real word examples in the lexicon.

Table 1.12 Rhyme structures in Hai-lu Hakka (Chen, 2000)

CV	CVV/CVC	CVVV/CVVC	Syllabic nasal
i	ia	iet	ŋ̩
e	io	ien	
ɨ	iu	iau	
a	im	iap	
o	in	iak	
u	ip	iam	
	it	iaŋ	
	eu	ioi	
	em	ion	
	en	ioŋ	
	ep	iot	
	et	iok	
	ai	iun	
	au	iuŋ	
	am	iut	
	an	iuk	
	aŋ	uen	
	ap	uai	
	at	uan	
	ak	uaŋ	
	oi	uat	
	on	uak	
	oŋ		
	ot		
	ok		
	ui		
	ua		
	un		
	uŋ		
	ut		
	uk		

2.3 Discussion on the Three Studies

Among the previous phonological studies summarized as in 2.2, three researchers agree that there are six underlying vowels in Hai-lu Hakka. When it comes to the complicated rhyme structure of Hai-lu Hakka, all the three researchers provide different opinions of rhyme structure. Their analyses differ mostly in the number and the phonetic properties of surface vowels of Hai-lu Hakka.

2.3.1 Hai-lu Hakka Underlying Vowels

First, concerning Hai-lu Hakka underlying vowels, all three scholars agree that there are six underlying vowels in the phonological system of Hai-lu Hakka. Namely, the high front unrounded vowel /i/, the mid front unrounded vowel /e/, the high mid unrounded vowel /ɨ/, the low mid unrounded vowel /a/, the mid back rounded vowel /o/, and the high back rounded vowel /u/.

Those different ideas on the allophones of the underlying vowels are provided in Table 1.13

Table 1.13 Allophones of single vowels

Underlying vowels	Surface vowel phone variants		
	Yang (1957)	Lo (1990)	Chen (2000)
/i/	[i] [ɪ]	[i][j]	[i]
/ɨ/	[ɿ][ʒ]	[ɿ][ə]	[ɨ]
/e/	[e][e̞]	[e]	[e]
/a/	[a][ä][e̞][ɑ]	[a]	[a]
/o/	[o][ɔ][o̜]	[o]	[o]
/u/	[u] [ʊ]	[u]	[u]

2.3.2 Hai-lu Hakka Surface Vowels

Basically, they all agreed that there are monophthongs, diphthongs, and triphthongs in the vowel system of Hai-lu Hakka. However, all the three researchers provide different opinions of the number and the phonetic properties of surface vowels of Hai-lu Hakka. The comparison of the three authors is offered in Table 1.14.

Table 1.14 Hai-lu Hakka surface vowels

		Yang (1957)	Lo (1990)	Chen (2000)
Monophthong	i e ɨ a u o			
Diphthong	ie io iu eu ai au ua	ia oi ui	ue	oi ui ue
Triphthong	iau uai	iai	iai ioi	ioi

For Hai-lu Hakka surface vowels, the three researchers Yang (1957), Lo (1990), and Chen (2000) agree that there are six single vowels: [i], [e], [ɨ], [a], [u], and [o]. As for diphthongs, they agree that there are seven diphthongs, namely [ie], [io], [iu], [eu], [ai], [au], and [ua]. In addition to the seven diphthongs, Yang (1957) and Chen (2000) all think that there are [oi] and [ui], Lo (1990) and Chen (2000) agree that there is [ue], and Yang (1957) proposes another diphthong [ia].

As for triphthongs, three researchers agree that there are two triphthongs, namely [iau] and [uai] in the phonological system of Hai-lu Hakka. Yang (1957) proposes that there is still another triphthong [iai]. Unlike Yang (1957), Chen (2000) thinks that the third triphthong is [ioi]. Lo (1990) proposes that there are four triphthongs: [iai], [ioi], [iau], and [uai].

2.3.3 Hai-lu Hakka Rhyme Structure

Since the three authors make different claims about the number of surface vowels of Hai-lu Hakka, they also disagree in the number of types of possible rhyme combination. According to Yang's studies (1957), combined with nasals and stops, there are 60 types of rhymes in Hai-lu Hakka, and 61 types in Si-xian Hakka, by adding "ieu." According to the analysis in Lo (1990), there are 63 types of rhymes in Hai-lu Hakka. In Chen's (2000) observation of Hai-lu Hakka spoken in Jhudong, Hsinchu County, there are 59 types of rhyme structure. Chen (2000) observed that some rhyme combinations are disappearing gradually, and this claim is not mentioned in Yang (1957), and Lo (1990) does mention that some rhyme combinations occur only in colloquial vocabulary.

2.4 Acoustic Theory and Application on Vowels

In this section, first, an introduction to acoustic theory and the basic principle of acoustic analysis of speech, the acoustic characteristics of vowel quality and the relationship between the vowel quality and the formant frequencies will be introduced in 2.4.1.

Secondly, studies on speech sound with the acoustic method on vowels of different languages in the world will be introduced in 2.4.2. The acoustic method of measuring the first two formants as the vowel quality has been widely applied to the study of languages worldwide, and the surveys of the complete set of surface vowel in the world's languages, including French, German, and Taiwanese Southern Min, Mandarin, and Hakka.

2.4.1 Introduction for acoustic characteristics of vowels

This section introduces vowel quality and the acoustic characteristics of vowels. A vowel is produced with the vibration of the vocal tract and the resonance of the oral cavity, and sometimes involves the resonance of the nasal cavity, too. A vowel is articulated without major constrictions and obstructions. The quality of a vowel depends on its overtone structures. A vowel simultaneously contains a number of different pitches, and these characteristic overtones are called formants of the vowels. The lowest is the first formant (F1), the second lowest the second formant (F2), and so on.

Formants are the resonances of the vocal tract. The air in the vocal tract is set in vibration by the pulses of air from the vocal folds. Every time they open and close, the air in the vocal tract above them will be set in vibration. Since the vocal tract has a complex shape, the air within it will vibrate in more than one way. We can consider the body of air behind the raised tongue to be vibrating in one way, and the body of air in front of it to be vibrating in another (Ladefoged, 1993, 1996, 2000, 2001, 2006).

There are some rules for describing the relation of vowels, formants and tongue positions. The frequency of F1 is lowered by any constriction of in the front half of the vocal tract, and the greater the constriction the more F1 is lowered. The frequency of F2 tends to be lowered by a back tongue constriction, and the greater constriction the more F2 is lowered. The frequency of F2 is raised by a front constriction, and the greater the constriction is, the more F2 is raised. Vowels are largely distinguished by the first two formants. In general, F1 varies mostly with tongue height and F2 with tongue advancement. Low vowels have higher F1 frequency and high vowels have lower F1 frequency. Back vowels have a lower F2 and typically a smaller F2－F1 difference, whereas front vowels have a relatively higher F2 frequency and a larger F2 －F1 difference. Rounded vowels have a lower F2 frequency compared to their unrounded counterparts. Higher formants, e.g., F3 and F4, vary a great deal from speaker to speaker. Though they are not uniquely determined for each speaker, they are certainly indicative of a person's voice quality (Bao, 1984; Kent & Read, 1992; Ladefoged, 1993).

However, it is important that these values are offered to indicate trends but not absolute values, because formant values may change from speaker to speaker. Factors such as age and sex are important because they determine vocal tract length. Generally speaking, formants of children are highest in frequency, women's are intermediate, and formants of men's are lowest in frequency (Peterson & Barney, 1952; Bao, 1984; Kent & Read, 1992). Other variables that affect acoustic properties include speech style (Johnson, Flemming & Wright, 1993) and dialect (Peterson & Barney, 1952; Holden & Nearey, 1986).

Gender differences can also be observed from acoustic vowel spaces (Hillenbrand et al., 1995). As a tendency, male vowel quality has lower formant frequencies than its female congener. Another apparent difference is that the female vowel space is larger than the male space, that is, the female vowel qualities stake out a larger acoustic area (Childers & Wu 1991, Peterson & Barney 1952, Wu & Childers 1991). This phonetic difference between males and females may result from their different vocal tract length. The average length of the adult female vocal tract (the distance from the vocal folds to the lips) is on average 14–14.5 cm, and the average male vocal tract is 17–18 cm.

2.4.2 Acoustic studies on vowels of world's languages

Acoustic phonetics is a technical area of linguistics. It is to study the sound waves made by human vocal organs for communication. Phoneticians depict and analyze sound waves using machines and computer programs. It is concerned with speech sounds as physical events with measurable properties such as duration and energy. In Acoustic phonetics studies, the spectrogram of speech sounds has been frequently used since 1950s. The acoustic method is a good tool in investigating language variation, especially the variation in vowel. Since vowels are not distinct as consonants are, the concrete method of acoustic analysis provides an objective solution to record and analyze the variants of vowels.

The acoustic method of measuring the first two formants as the vowel quality has been widely applied to the study of languages worldwide. Ladefoged and Maddieson (1996) employed the acoustic method in the sound of the world's languages. Other surveys of vowels by acoustic approach in the world's language, includes Danish, (Fischer-Jorgensen, 1972); Dutch, (Pols, Tromp & Plomp, 1973), American English (Peterson & Barney, 1952; Olive, Greenwood & Coleman, 1993; Hillenbrand, Getty, Clark & Wheeler, 1995; Ladefoged, 2006), British English (Wells 1963), Japanese (Chiba & Kajiyama, 1941), Korean (Yang, 1992; Yuen, 2001), Russian (Halle, 1959) Swedish (Fant, 1973), Beiging Mandarin (Howie, 1976, Wu 1986, Zee 2000, 2001; Zee & Lee 2001), Cantonese (Zee, 1999),Taiwanese Southern Min (Myers & Tsay 2003), Taiwan Mandarin (Liu, Zeng & Cao, 1999; Fon, Chiang & Chueng, 2004; Pan, Li, Lee, Huang & Tsou, 200), and Hakka (Liang, 2004; Huang, 2004; Deng, 2006; Zee & Lee, 2008; Zee & Lee, 2009).

2.5 Acoustic Studies of Hakka

Some research had been dedicated to the acoustic studies on Hakka. In this section, the previous acoustic studies on dialects of Hakka spoken in Taiwan and Mainland China will be introduced.

2.5.1 Acoustic Studies of Hakka Spoken in Taiwan

In this section, acoustic studies in Taiwan will be introduced. In this section, we focus on types of Hakka dialect spoken in Taiwan area, mainly Si-xian Hakka in different areas. Former acoustic research in studying speech sounds focus on various topics, including consonants and vowels (Liang 2004 for consonants and vowels of Si-xian Hakka spoken in Meinung Cheng et al. 2009 for vowel pattern of Si-xian Hakka), tones and vowels (Huang 2004 for tones and vowels of Si-xian Hakka spoken in Meinung).

Liang (2004) conducted an acoustic research in his thesis. He describes the acoustic characteristics and set up models of acoustic nature of Hakka vowels and consonants. His study focused on the Si-xian Hakka spoken in Meinung. The acoustic cues are the first and second formant frequencies, Voice Onset Time (VOT), release burst, turbulence noise, nasal murmur and formant transition. The results of Liang's (2004) study show that the Hakka vowel /i/ is the most front and highest vowel (even higher than /u/), and the vowel /ɨ/ is a central and high vowel (approximate to the height of /u/), and the vowel /a/ is a central and low vowel. With regard to vowel height and F0 frequency, the higher vowel is, the higher F0 frequency it shows in the analysis. In addition, compare to the unchecked tones, the tongue positions of six vowels on checked tones seem to have the tendency of neutralization. Liang (2004) concluded that, generally, the Hakka vowels /i, e, a, o, u/ are similar to the English vowels /i, e, a, o, u/ (Ladeforged & Maddieson, 1996), and only Hakka /a/ is produced more front than English /a/.

Huang (2004) investigated the physical realities of the Hakka tones and vowels by taking acoustic and statistical approaches. He targeted the Hakka spoken at Meinong, a township in the Kaohsiung County. The quantitative information of the citation and sandhi tones of Hakka come from four acoustic cues: fundamental frequency (F0), F0 slope, duration, and intensity. With regard to vowels, he also examined the influence of vowel height on the fundamental frequency and the gender differences of the four cues.

Deng (2006) conducted an acoustic study on the Hakka palatalized fricatives. The consonant characteristics are explored with the friction duration time, LPC frequency and formant transition to gain the consonant specifics among the fifteen Mandarin, Si-xian Hakka Hai-lu fricative consonants. Deng's (2006) study utilized the field study to collect sounds among the six Hakka dialects. She utilized Praat system to fetch the information of acoustic cues such as the fundamental frequency, the noise duration time, the intensity and the LPC frequency for statistical analyses.

Cheng et al. (2009) explored the systematicity and variability of the vowel pattern in Sixian Hakka from an acoustic perspective. In terms of social variables as gender and age, Cheng et al (2009) found that females' vowel space is comparatively larger than males'. Furthermore, research results show the apical vowel [ɨ] moves gradually in the direction toward [i]. The younger the informant is, the greater approximation to [i]. Cheng et al. (2009) provided phonological explanations for this gradual pattern change from four perspectives: markedness, vowel system, speech perception and language evolution.

2.5.2 Acoustic Studies of Hakka Spoken in Mainland China

This section introduces the acoustic studies of Hakka spoken in Mainland China. Zee & Lee conducted a series of acoustic studies on Yongding Hakka vowels. They examine the effect of vowel duration on formant frequencies, and analysis of tone and tone sandhi (Zee & Lee, 2008), and the vowel space and the gender differences of the three vowels /i a ɨ/ of Yongding Hakka (Zee & Lee, 2011).

Zee & Lee (2008) conducted studies on the effect of vowel duration on formant frequencies, and analysis of tone and tone sandhi in Hakka dialect, based on the acoustic data from Hakka spoken in Mainland China. In their studies on the effect of vowel duration on formant frequencies, they examine whether more schwa-like formant frequencies as vowel duration is shortened.

Zee & Lee (2011) conducted studies on the Yongding Hakka vowels. Yongding Hakka has a vowel system of three vowel phonemes /i a ɨ/. Their results show for both genders, F2 for [a] is significantly higher for Yongding than other Chinese dialects.

2.6 Summary

In previous studies, the acoustic approach had been widely applied to the investigation of speech sounds of languages in the world. Some studies have been dedicated to the acoustic properties of speech sounds of Hakka dialects, but most of the former acoustic research in studying speech sounds focus on the phonological system of Si-xian dialect.

Since there are scarcely any studies focusing on the acoustic studies of Hai-lu Hakka segments, the aim of this present study is to investigate the acoustic nature of Hai-lu Hakka vowels, and hope to provide reference materials for further research on speech cognition, production, perception, pathological diagnosis and correction of speech disorders, and Hakka language teaching.

CHAPTER III

METHODOLOGY

3.1 Subjects

A total of six subjects were invited to participate in the study. The subjects were aged from fifty-three to seventy-eight years old. Three of them were male and the other three subjects were female. All of them were Hakkaese and were brought up in Hakkaese families, and they speak Hai-lu Hakka as their mother tongue. Their birthplaces and living places are within Xinpu town, Hsinchu County. As for the language background of the subjects, all of the subjects are fluent in using Hai-lu Hakka, and one female subject is fluent in using Si-xian Hakka, too. All of the subjects can speak Taiwan Mandarin fluently. Most of them can understand Taiwanese Southern Min, but they cannot speak Taiwanese Southern Min fluently. Four of the subjects have learned some English in school but most are considered not fluent by self evaluation. For the detailed data and language background of the subjects, please see Appendix I.

3.2 Materials

This section presents the materials in the present study, including design of testing words, and equipments.

3.2.1 Design of testing words

There were 32 test items in total in this study. The 32 test items include five types of syllable structure: CV, CVV, CVVV, CVC, and CVVC. During the experiment, the testing words were produced in two forms: the citation form and the sentence form. In the citation form, the test words were produced in individual syllables with several seconds of interval between syllables. As for the sentence form, the test words were produced in the short sentence [tshiaŋ24 ŋiam33 tshut5 ___ lia24 kai11 sɨ33 loi55] (Please say ____ this word), and there are intervals between these words.

Almost all of the testing words have the tone value [55], except for the words: [nie31] (meaning, *'蟻' ants*). Tone [55] is chosen for consistency purpose, and the other reason is that it is the most common tone value which has the most possible syllables in the lexicon. There are more possible syllables that include a greater variety of combinations of segments in the syllable final and could also be written down in Chinese characters. The rationale behind the selection of the same tone value for test items is because studies such as Howie (1976), Tsao & Yang (1984), and Hoole & Hu (2004) found that tones do have influences on the vowel quality. For example, Howie (1976) found syllables with high tones have higher vowel quality.

For the detailed test words involved in this study, please see Appendix II.

3.2.2 Equipments

This section introduces the equipments utilized in the present study. The sub-sections include the stimuli, the recording apparatus, acoustic analysis apparatus, and statistic software and vowel space plotting software.

3.2.2.1 Stimuli

Testing word cards were used as the stimuli for this study. The testing word cards were made of papers in 6cm × 12cm size. Characters of the testing words and carrier sentences that contain the testing words sized 72pts were printed in black New Ximing Font in the center of word cards. Since there were three practice cards for the citation section and three for the sentence section and 192 tokens for each subject, a total of 205 word cards were employed in this study.

3.2.2.2 Recording apparatus

The recording apparatus used in the present study was KAY Electronics' CSL 4100 speech analysis package, which is provided by the phonetic and psycholinguistic laboratory of the Graduate Institute of Linguistics, National Chengchi University.

One of the advantages of using KAY Electronics' CSL 4100 speech analysis package to record the speech sound is that it could convert the analog signals into digital signals with little distortion. Thus, it provides more convenience for the computer to edit, store, and analyze the speech sounds. The microphone was placed near the subjects' mouth in a distance during the recording, so that sounds could be recorded clearly, and still subjects felt comfortable. The whole recording section was stored as PCM, 11.025 kHz, 16 bits, monaural WAV sound files.

3.2.2.3 Acoustic analysis apparatus

The apparatus utilized in this study to analyze the record files is also KAY Electronics' CSL 4100 speech analysis package. KAY has been used widely in studies of acoustic analysis in the fields of acoustics, audiology, speech pathology, and acoustic phonetics because of its convenience in edit, store, and analyze.

3.2.2.4 Statistic software and vowel space plotting software

The statistic data will be processed with the *SPSS 11.0* (Statistics Package for Social Science, version 11.0) released by SPSS Inc. *SPSS* is one of the most widely used programs for statistical analysis in social sciences. The analysis method used in this study was descriptive statistics. Most of the vowel spaces or formant plots were plotted with the software Origin 6.0.

3.3 Procedures

This chapter introduces the procedures in this study. Section 3.3.1 describes the recording procedure, and the section presents the acoustic measurement of the vowels after collecting the data.

3.3.1 Recording

The subject was seated in a quiet room, and the recording apparatus was placed before the subjects on a table. There were sections of personal data filling and instruction before the recording begins. During the instruction section, the subjects will be informed of the requirements and things to be noticed in the recording. For the detailed personal data filling form for the subjects, please see Appendix III.

Each of the 32 words was printed on a card. A microphone was placed on a table in front of the subject's mouth. The distance between the subject's mouth and the microphone was approximately 15 cm. The recording system consisted of an IBM ThinkPad X200s laptop computer and one general extra microphone. The subjects were asked to read the words on the card aloud at a normal speaking rate. If any word was unfamiliar, the experimenter would explain the word or ask the subject to try to read it with the assistance of its phonetic transcription. No modelling of the sound production was provided by the experimenter.

After the instruction section, the recoding will further be divided into two sections: a citation form section and a sentence form section. Before each section, three practice word cards in the form of that section will be given to simulate the process in the recording. During each section, three piles of word cards will be given to the subjects since three tokens for each testing word were required, and consequently three rounds of the reading of word cards were needed. To ensure that the reading speed was generally controlled at similar pace, the word cards were presented to the subjects one by one by the experimenter rather than handled by the subjects themselves.

The subjects were asked to read the testing words in the speed of their ordinary conversation. The order of word cards was randomized in each round in order to prevent any possible patterns created by the order of the testing words. There will be short breaks between sections for the subjects to take a rest and for the experimenter to set up the recording instrument.

3.3.2 Acoustic measurements

In this section, we present the introduction to the acoustic measurement of six types of syllable structure: CV, CVV, CVC, CVVC, and CVVV. All the acoustic measurements were done by the help of Kay CSL 4100.

3.3.2.1 Acoustic measurement of CV

Figure 2.1 The spectrogram of [tʰi55] (meaning, *‘提’ ‘lift’*)

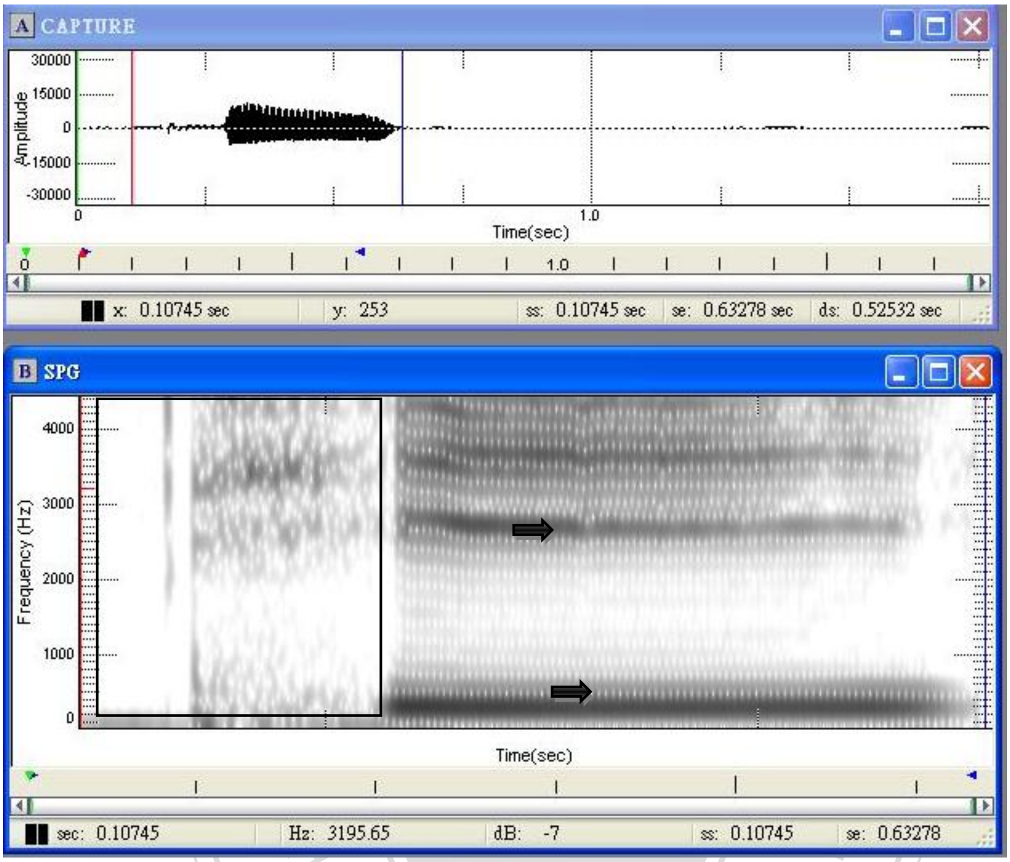


Table 2.1 Acoustic measurement of [tʰi55] (meaning, *‘提’ ‘lift’*)

	[tʰ]	[i]
Start time	0.1567 ms	0.29887 ms
End time	0.28953 ms	0.58017ms
F1		245Hz
F2		2820Hz

In CV syllable structure, the word [tʰi55] (meaning, *‘提’ ‘lift’*) is chosen as an example for acoustic analysis here. The spectrogram of [tʰi55] (meaning, *‘提’ ‘lift’*) is shown in Figure 2.1. [tʰi55] consists of the aspirated voiceless alveolar stop [tʰ] and the high front vowel [i]. We can identify the stop [tʰ] on the spectrogram by the burst between 0.1567 ms and 0.28953 ms. The stop [tʰ] is tagged as in the rectangle on the left of Figure 3.1.

Between 0.28953 ms 0.29887 ms, the sound is the combination of the stop [t^h] and the high front vowel [i], thus this part is excluded from our analysis of high front vowel [i]. The high front vowel [i] starts at about 0.29887 ms, and it ends at 0.58017ms. As the vowel is identified on the spectrogram, we then move the cursor on the left to the steady state of the vowel. The arrows show where the first formant and the second formant of high vowel [i] are. The F1 of high vowel [i] is about 245Hz, and the F2 value is about 2820Hz.

3.3.2.2 Acoustic Measurement of CVV

Figure 2.2 The spectrogram of [k^hia55] (meaning, *'佢' 'his'*)

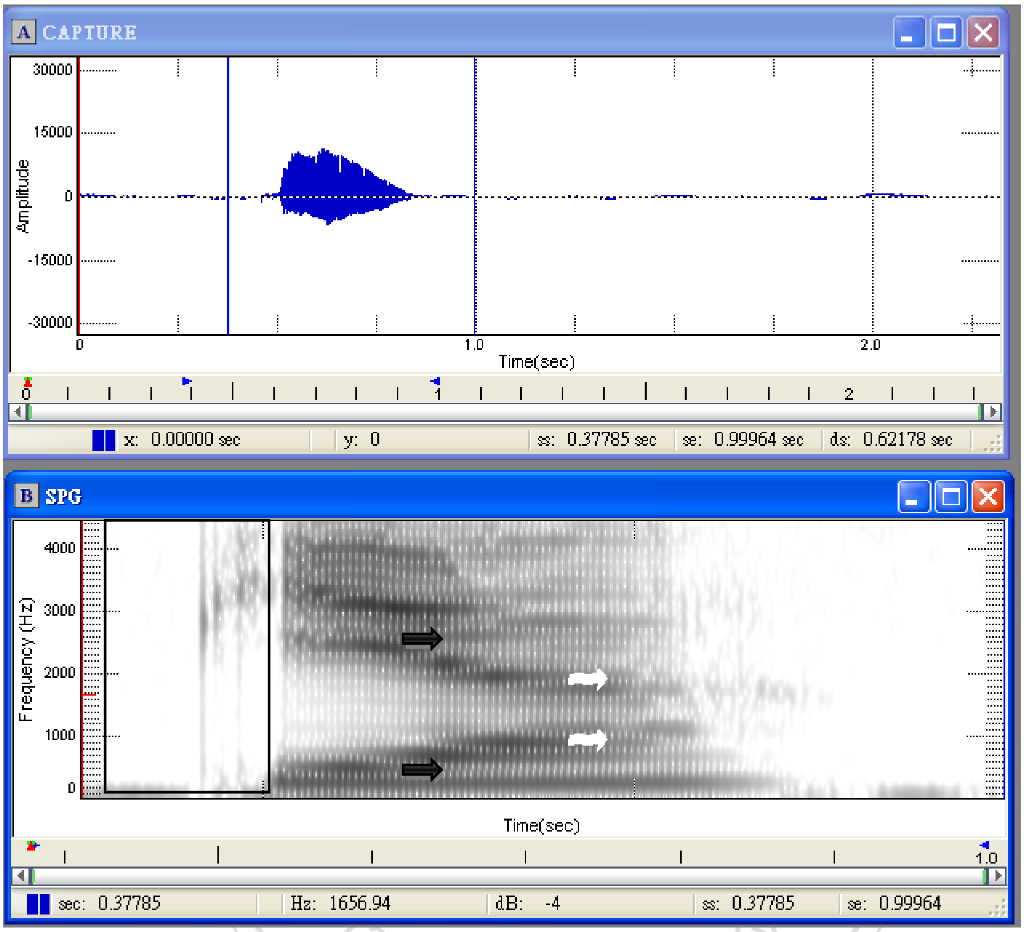


Table 2.2 Acoustic measurement of [k^hia55] (meaning, *'佢' 'his'*)

	[k^h]	[i]	[a]
Start time	0.45760 ms	0.51471 ms	0.65157 ms
End time	0.49855 ms	0.64295 ms	0.73885 ms
F1		560.81Hz	917.69Hz
F2		2421.68Hz	1962.83Hz

In CVV syllable structure, the word [k^hia55] (meaning, *'佢' 'him'*) is chosen as an example for acoustic analysis here. The spectrogram of [k^hia55] (meaning, *'佢' 'him'*) is shown in Figure 2.2. [k^hia55] consists of the aspirated voiced velar stop [k^h], the high front vowel [i], and the low central vowel [a]. We can identify the stop [k^h]

on the spectrogram by the burst between 0.45760 ms and 0.49855 ms. The stop [k^h] is tagged as in the rectangle on the left of Figure 3.2.

Between 0.49855 ms 0.51471 ms, the sound is the combination of the stop [k^h] and the high front vowel [i], thus this part is excluded from our analysis of high front vowel [i]. The high front vowel [i] starts at about 0.51471 ms, and it ends at 0.64295 ms. As the vowel is identified on the spectrogram, we then move the cursor on the left to the steady state of the vowel. The two black arrows show where the first formant and the second formant of high vowel [i] are. The F1 of high vowel [i] is about 560.81Hz, and the F2 value is about 2421.68Hz.

Between 0.64295 ms 0.65157 ms, there is the transition of the high front vowel [i] and the low central vowel [a], thus this part is excluded from our analysis of the two vowels. The low central vowel [a] starts at about 0.65157 ms, and it ends at 0.73885 ms. As the vowel is identified on the spectrogram, we then move the cursor on the left to the steady state of the vowel. The two white arrows show where the first formant and the second formant of low central vowel [a] are. The F1 of high vowel [i] is about 917.69Hz, and the F2 value is about 1962.83Hz.

3.3.2.3 Acoustic measurement of CVVV

Figure 2.3 the spectrogram of [tʰiau55] (meaning, *'條' 'a long narrow strip'*)

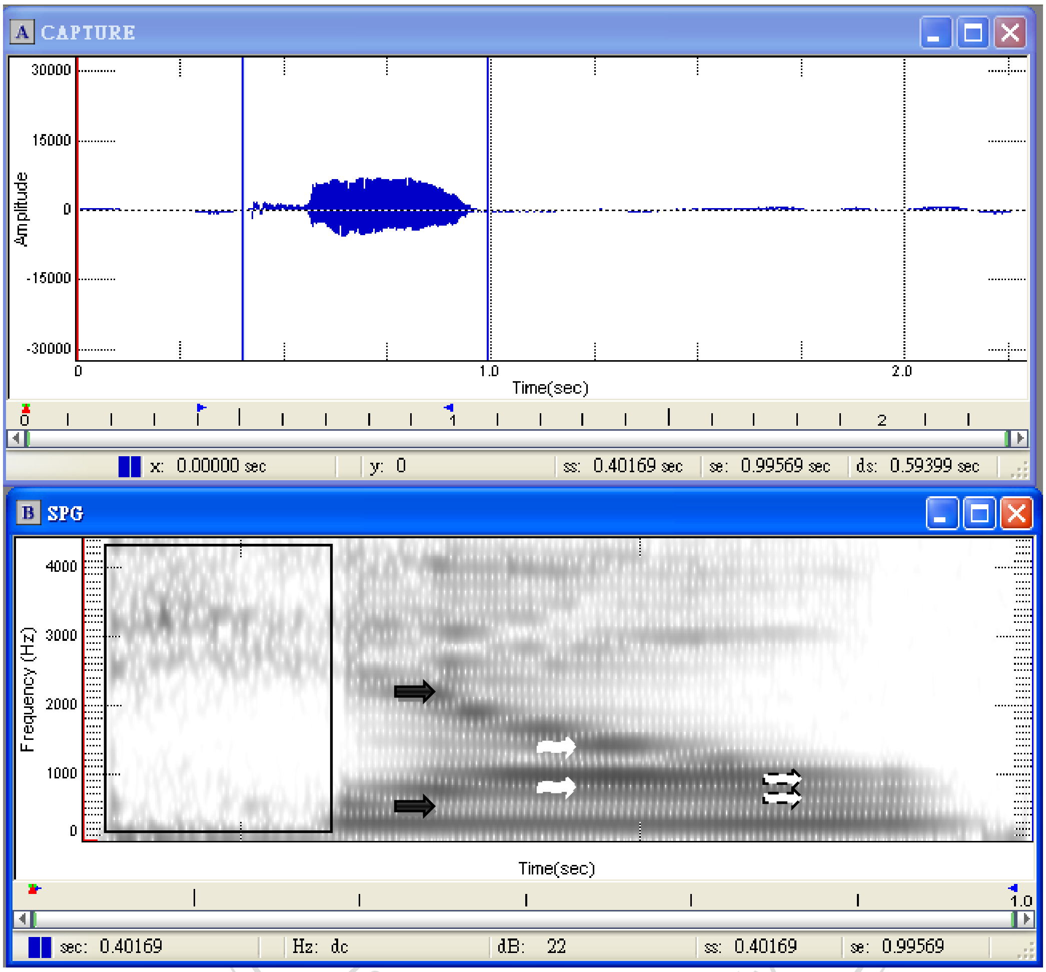


Table 2.3 Acoustic measurement of [tʰiau55] (meaning, *'條' 'a long narrow strip'*)

	[tʰ]	[i]	[a]	[u]
Start time	0.41672 ms	0.58200 ms	0.65913 ms	0.72524 ms
End time	0.56397 ms	0.63408 ms	0.71622 ms	0.91155 ms
F1		676.67Hz	863.33Hz	700.00Hz
F2		2100.00Hz	1656.00Hz	933.33Hz

In CVVV syllable structure, the word [tʰiau55] (meaning, *'條' 'a long narrow strip'*) is chosen as an example for acoustic analysis here. The spectrogram of [tʰiau55] (meaning, *'條' 'a long narrow strip'*) is shown in Figure 3.3. The syllable [tʰiau55] consists of the aspirated voiceless alveolar stop [tʰ], the high front vowel [i], the low central vowel [a], and the high back rounded vowel [u]. We can identify the stop [t^h] on the spectrogram by the burst between 0.41672 ms and 0.56397 ms. The stop [t^h] is tagged as in the rectangle on the left of Figure 3.3.

Between 0.56397 ms and 0.58200 ms, the sound is the combination of the stop [t^h] and the high front vowel [i], so this part is excluded from our analysis of the mid back rounded [i]. The high front vowel [i] starts at about 0.58200 ms, and it ends at 0.63408 ms. As the vowel is identified on the spectrogram, we then move the cursor on the left to the steady state of the vowel. The two black arrows show where the first formant and the second formant of the high front vowel [i] are. The F1 of the high front vowel [i] is about 676.67 Hz, and the F2 value is about 2100.00 Hz.

Between 0.63408 ms. and 0.65913 ms, there is the transition of the high front vowel [i] and the low central vowel [a], and thus this part is excluded from our analysis of the two vowels. The low central vowel [a] starts at about 0.65913 ms, and it ends at 0.71622 ms. As the vowel is identified on the spectrogram, we then move the cursor on the left to the steady state of the vowel. The two white arrows show where the first formant and the second formant of low central vowel [a] are. The F1 of high vowel [i] is about 863.33 Hz, and the F2 value is about 1656.00 Hz.

Between 0.71622 ms and 0.72524 ms, there is the transition of the low central vowel [a] and the high back rounded vowel [u], and thus this part is excluded from our analysis of the two vowels. The high back rounded vowel [u] starts at about 0.72524 ms, and it ends at 0.91155 ms. As the vowel is identified on the spectrogram, we then move the cursor on the left to the steady state of the vowel. The two arrows with dashed line show where the first formant and the second formant of high back rounded vowel [u] are. The F1 of high back rounded vowel [u] is about 700.00Hz, and the F2 value is about 933.33Hz.

3.3.2.4 Acoustic measurement of CVC

Figure 2.4 The spectrogram of [tʰot55] (meaning, *'脫' 'get off'*)

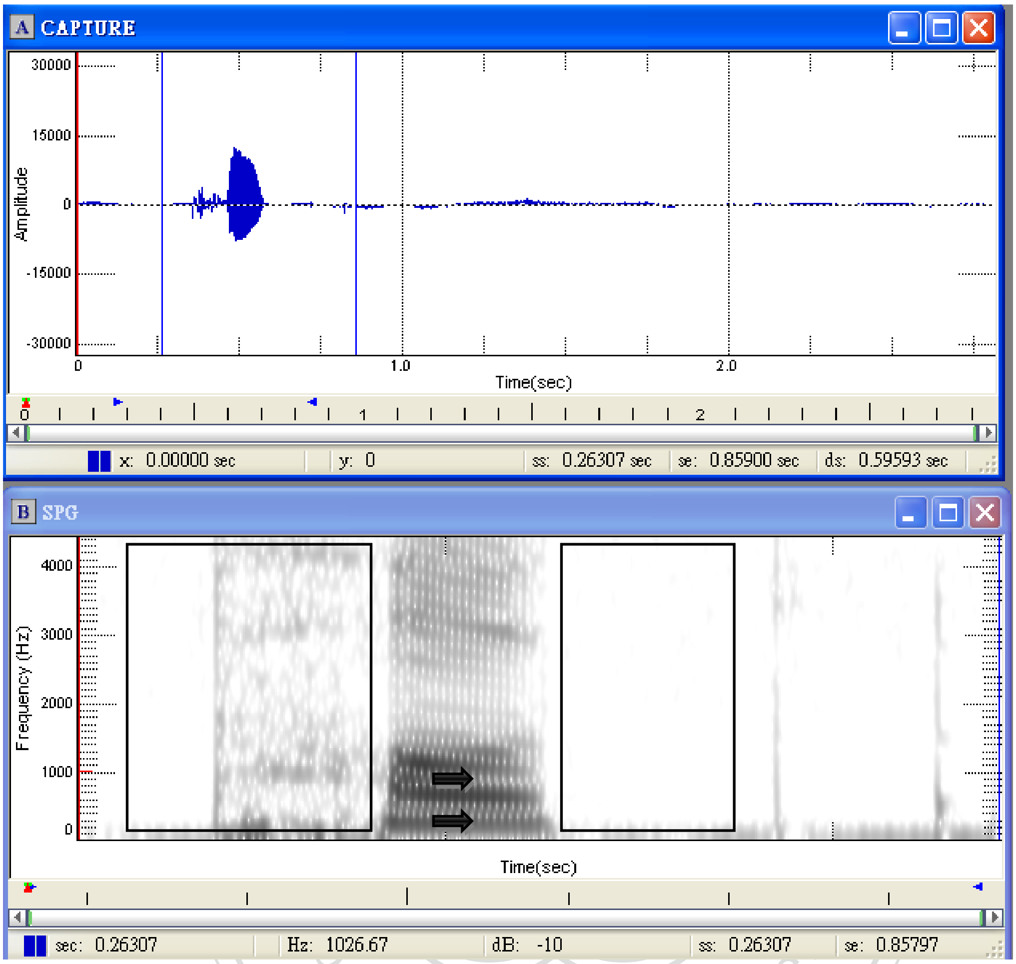


Table 2.4 Acoustic measurement of [tʰot55] (meaning, *'脫' 'get off'*)

	[tʰ]	[o]	[t]
Start time	0.34820 ms	0.46966 ms	0.56728 ms
End time	0.46058 ms	0.55706 ms	0.63652 ms
F1		256.67Hz	
F2		700Hz	

In CVC syllable structure, the word [tʰot55] (meaning, *'脫' 'get off'*) is chosen as an example for acoustic analysis here. The spectrogram of [tʰot55] (meaning, *'脫' 'get off'*) is shown in Figure 2.4. The syllable [tʰot55] consists of the aspirated voiceless alveolar stop [tʰ], the mid back rounded [o], and the unaspirated voiceless alveolar stop [t]. We can identify the stop [tʰ] on the spectrogram by the burst between 0.34820 ms and 0.46058 ms. The stop [tʰ] is tagged as in the rectangle on the left of Figure 2.4.

Between 0.46058 ms 0.46966 ms, the sound is the combination of the stop [tʰ] and the mid back rounded [o], so this part is excluded from our analysis of the mid back rounded [o]. The mid back rounded [o] starts at about 0.46966 ms, and it ends at 0.55706 ms. As the vowel is identified in the spectrogram, we then move the red cursor on the left to the steady state of the vowel. The two black arrows show where the first formant and the second formant of the mid back rounded [o] are. The F1 of the mid back rounded [o] is about 256.67Hz, and the F2 value is about 700Hz.

Between 0.55706 ms and 0.56728 ms, there is the transition of the mid back rounded [o] and the unaspirated voiceless alveolar stop [t], and thus this part is excluded from our analysis of the vowel. The unaspirated voiceless alveolar stop [t] starts at about 0.56728 ms, and it ends at 0.63652 ms.

3.3.2.5 Acoustic measurement of CVVC

Figure 2.5 The spectrogram of [t^hiap55] (meaning, *'帖' 'a handwritten copy'*)

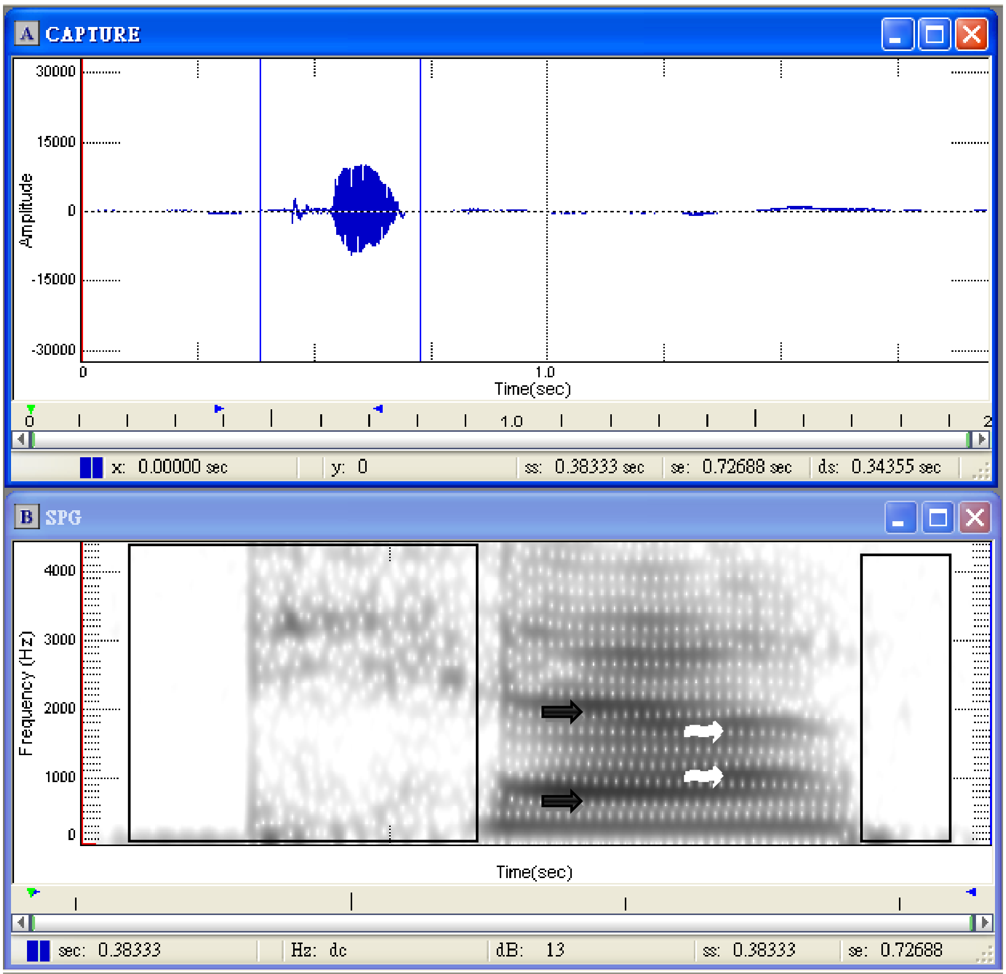


Table 2.5 Acoustic measurement of [t^hiap55] (meaning, *'帖' 'a handwritten copy'*)

	[t^h]	[i]	[a]	[p]
Start time	0.44591 ms	0.53339 ms	0.60555 ms	0.67707 ms
End time	0.48986 ms	0.59278ms	0.66302 ms	0.71411 ms
F1		560.00Hz	956.67Hz	
F2		2006.67Hz	1656.00Hz	

In CVVC syllable structure, the word [t^hiap55] (meaning, *'帖' 'a handwritten copy'*) is chosen as an example for acoustic analysis here. The spectrogram of [t^hiap55] (meaning, *'帖' 'a handwritten copy'*) is shown in Figure 2.5. The syllable [t^hiap55] consists of the aspirated voiceless alveolar stop [t^h], the high front vowel [i], the low central vowel [a], and the unaspirated voiceless bilabial stop [p]. We can identify the stop [t^h] on the spectrogram by the burst between 0.44591 ms and 0.48986 ms. The stop [t^h] is tagged as in the rectangle on the left of Figure 2.5.

Between 0.48986 ms and 0.53339 ms, the sound is the combination of the stop [t^h] and the high front vowel [i], and thus this part is excluded from our analysis of the high front vowel [i]. The high front vowel [i] starts at about 0.53339 ms, and it ends at 0.55706 ms. As the vowel is identified on the spectrogram, we then move the red cursor on the left to the steady state of the vowel. The two black arrows show where the first formant and the second formant of the high front vowel [i] are. The F1 of the high front vowel [i] is about 560.00Hz, and the F2 value is about 2006.67Hz.

Between 0.55706 ms and 0.60555 ms, there is the transition of the high front vowel [i] and the low central vowel [a], and thus this part is excluded from our analysis of the two vowels. The low central vowel [a] starts at about 0.60555 ms, and it ends at 0.66302 ms. As the vowel is identified in the spectrogram, we then move the red cursor on the left to the steady state of the vowel. The two white arrows show where the first formant and the second formant of low central vowel [a] are. The F1 of high vowel [i] is about 956.67Hz, and the F2 value is about 1656.00Hz.

Between 0.66302 ms and 0.67707 ms, there is the transition of the mid back rounded [o] and the unaspirated voiceless bilabial stop [p], and thus this part is excluded from our analysis of the vowel. The unaspirated voiceless bilabial stop [p] starts at about 0.67707 ms, and it ends at 0.71411 ms.

CHAPTER IV

FINDINGS AND DISCUSSIONS

4.1 Overview of the data

In this chapter, we present the results of the study. Among the 32 test words, one test word [ts^{h}ioi55] is considered to be no longer spoken as the phonetic transcription in Hakka dictionary, and the six subjects pronounce it as [ts^{h}oi55] instead, and thus this test word is excluded from present study. Besides [ts^{h}oi55], another test word [iai55] can only be spoken correctly by two of the six subjects.

Excluding the test word [ts^{h}oi55], there are 31 test words, and therefore 186 tokens (31x3x2) are spoken by six subjects, and we expect 1116 (31 test words x3 repetitions x 2 conditions x 6 speakers) acoustic data. However, the test word [iai55] can only be pronounced correctly by two of the six subjects, and the rest four subjects pronounce [ʒai55] instead. We have to minus 24 (1 test word x 3 repetitions x 2 conditions x 4 speakers) acoustic data. Finally, we get 1092 reliable recording data under study.

After the recording was done, all the recording data were analyzed by using KAY CSL 4100. Among the 1092 recording data, there were 6 blurred data that are unreadable to the software, thus they are also excluded from the present analysis, and therefore there are totally 1086 reliable acoustic data under study.

After 1086 acoustic data are analyzed by using KAY CSL 4100 and processed by *SPSS 11.0*, the mean level of frequency of F1 and F2 value of the six monophthongs, eleven diphthongs and three triphthongs are presented in the following sub-sections. Section 4.2 presents the acoustic analysis and the spectrogram of six monophthnogs [i], [e], [ɨ], [a], [o], and [u]. Section 4.3 presents the acoustic analysis and the spectrogram of eleven diphthnogs [ie], [ia], [io], [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua]. Section 4.4 presents the acoustic analysis and the spectrogram of three triphthnogs [iai], [iau], and [uai]. The summary of the findings is provided in section 4.5.

4.2 Acoustic analysis of monophthongs

This section presents the acoustic analysis of the six monophthongs [i], [e], [ɨ], [a], [o], and [u]. To describe the location of six monophthongs precisely in a phonetic vowel space, we design twelve test words that place six monophthongs [i], [e], [ɨ], [a], [o], and [u] in both CV and CVC structure. The twelve test words are [t^hi55], [k^he55], [ts^hɨ55], [k^ha55], [t^ho55], [t^hu55], [tit55], [tet55], [ʒɨt55], [kat55], [t^hot55], and [kut].

The mean F1 and F2 values (Hz) of 6 monophthongs of Hai-lu Hakka in all subjects are presented in section 4.2.1, and the spectrogram analysis of six monophthongs is provided in section 4.2.2.

4.2.1 Formant frequencies of monophthongs

This section gives the acoustic data analysis of the six monophthongs. After acoustic data are analyzed by using KAY CSL 4100, the mean level of frequency of F1 and F2 value of the six monophthongs from six subjects is provided in Table 3.1

Table 3.1 Mean F1 and F2 values (Hz) of 6 monophthongs of Hai-lu Hakka in all subjects

		Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Mean	SD
[i]	F1	295.11	310.54	305.02	280.57	275.47	270.05	289.46	16.6
	F2	2987.17	3257.02	3100.11	2563.06	2645.47	2635.17	2864.67	288.5
[e]	F1	560.78	610.32	575.00	497.85	450.19	505.12	533.21	60.0
	F2	2655.19	2690.11	2877.95	2416.00	2317.46	2399.47	2559.36	215.6
[ɨ]	F1	448.72	470.00	503.56	410.45	398.78	367.35	433.14	50.2
	F2	1809.76	1811.53	1745.22	1578.35	1303.01	1637.34	1647.53	193.1
[a]	F1	1312.58	1596.12	1458.69	1058.32	986.21	958.63	1228.4	266.7
	F2	1785.22	1989.54	1874.01	1298.11	1346.38	1250.87	1590.69	328.0
[o]	F1	623.47	615.02	633.12	589.21	601.08	582.17	607.34	19.9
	F2	1103.00	1258.25	1006.38	1102.56	987.36	954.36	1068.5	111.2
[u]	F1	489.21	501.28	517.65	403.65	399.01	358.11	444.81	66.0
	F2	753.21	788.96	771.02	692.27	721.01	717.11	740.59	36.6

Table 3.1 shows the mean values of F1 and F2 of six monophthongal vowels [i, e, ɨ, a, o, u] in Hai-lu Hakka. The acoustic data indicates that the formant patterns of [i], [e], [ɨ], [a], [o] and [u] for the male speakers (subject 4, subject 5, and subject 6) are similar to those for the female speakers (subject 1, subject 2, and subject 3), respectively. The overall formant frequency values, particularly the F1 and F2 values, of the vowels for the male speakers are lower than those for the female speakers as expected. It is due to the differences in

vocal tract dimensions between male and female speakers.

The distribution of the mean F1 and F2 value of six monophthongs in the vowel space is shown in Figure 3.1

Figure 3.1 The distribution of the mean F1 and F2 value of six monophthongs from six subjects in the vowel space

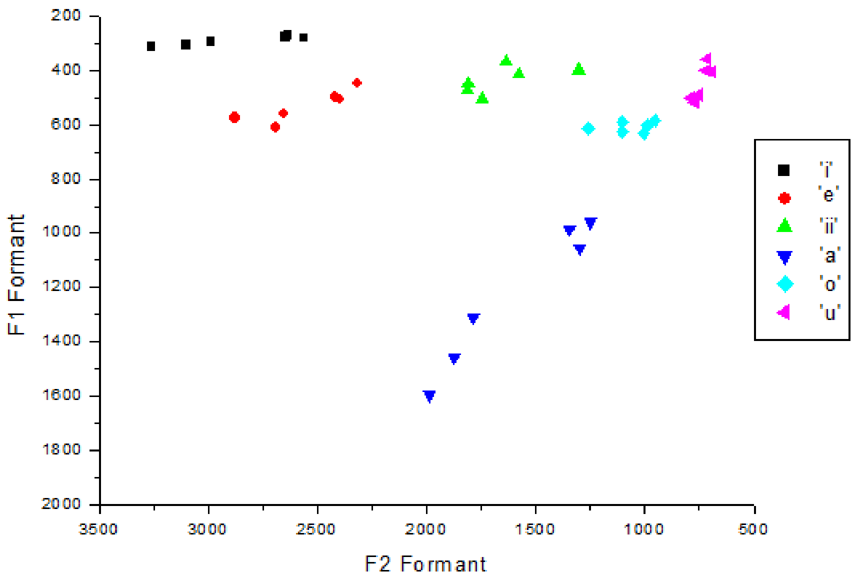
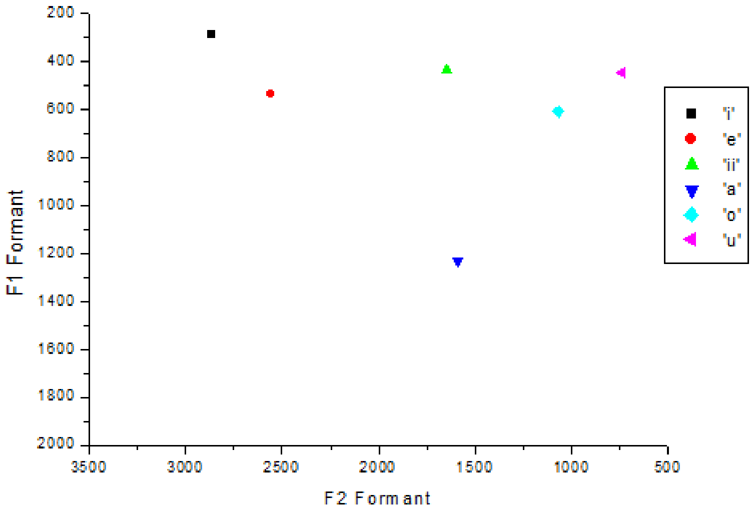


Figure 3.2 The mean F1 and F2 value of six monophthongs from six subjects in the vowel space



Among the six vowels, the high front vowel [i] has the lowest F1 and the highest F2, because F1 is lowered by the constriction of in the front half of the vocal tract, and F2 is higher when it is a front vowel. Since F2 corresponds to vowel front/backness, the F2 value of the mid front vowel [e] only second to that of [i]. The high mid vowel [ɨ] has a low F1 value since it is a high vowel. Since the tongue position of [ɨ] is following [i] and [e], it is lower than [i] but higher than [e].

Since F1 corresponds to vowel height, the low central vowel [a] has the highest F1 value among the six vowels of Hai-lu Hakka because the position of [a] is the lowest among the six. As for the second formant, F2 corresponds to the front/back dimension of tongue position. The F2 of low central [a] is nearly the same as that of high central vowel [ɨ]. Since F1 corresponds to vowel height and the mid fornt [e] and the mid back [o] are all mid vowels, [o] has the F1 value very close to that of [e]. As for the second formant, F2 corresponds to the front/back dimension of tongue position. The F2 of back vowel [o] is much lower than that of mid front vowel [e], and the lip-rounding feature further lowers the F2 value of [o].

The high back vowel [u] has the lowest F2 since F2 tends to be lowered by a back tongue constriction, and [u] is pronounced with back tongue position. The F1 of [u] is also low, since high vowels have lower F1 value. Since the lips are rounded by speaker at the same time, F2 is lowered even more.

4.2.2 Spectrogram of monophthongs

This section presents how six Hai-lu Hakka vowels [i], [e], [ɨ], [a], [u], and [o] are presented as in a spectrogram. From all of the six subjects and 1086 reliable data, the spectrogram presented here are taken from one female speaker who is labeled as ‘subject 2’. To see the detailed description of the subjects, please see appendix I.

The spectrogram of CV structure [t^{h}i55], [k^{h}e55], [ts^{h}ɨ55], [k^{h}a55], [t^{h}o55], and [t^{h}u55] are presented in Figure 3.3. The spectrogram of CVC structure [tit55], [tet55], [ʒɨt55], [kat55], [t^{h}ot55], [kut] is presented in Figure 3.4.

Figure 3.3 The spectrogram of CV structure [t^{h}i55], [k^{h}e55], [ts^{h}ɨ55], [k^{h}a55], [t^{h}o55], and [t^{h}u55]

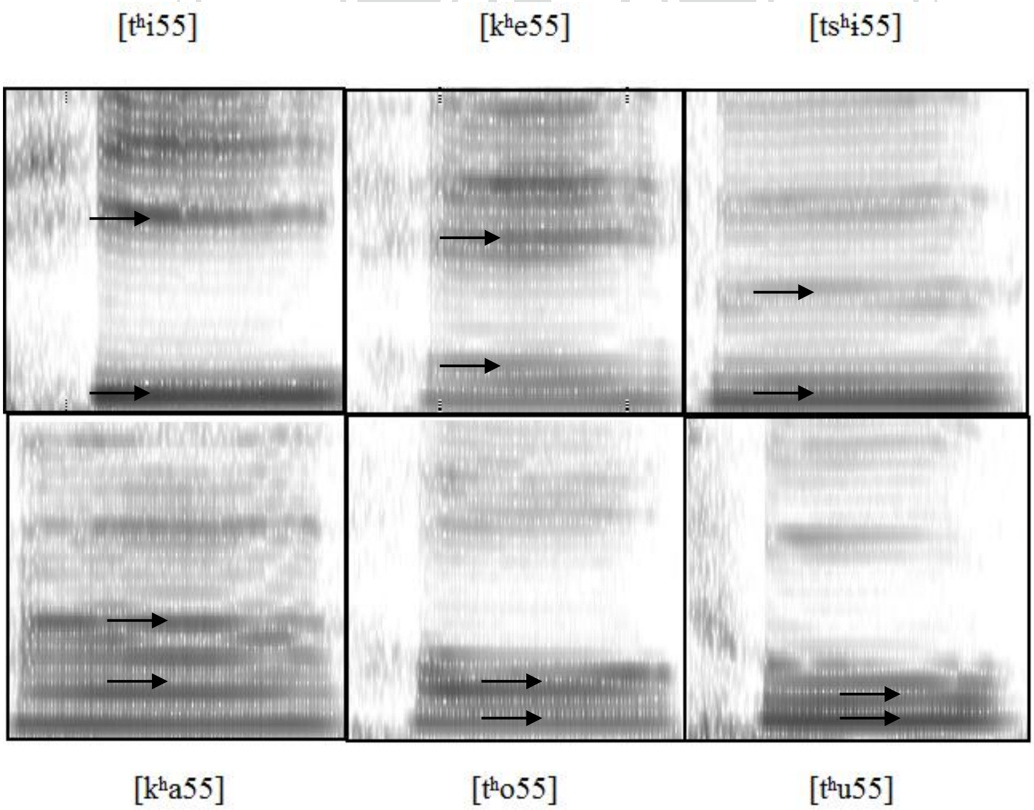


Figure 3.4 The spectrogram of CVC structure [tit55], [tet55], [ʒɨt55], [kat55], [t^hot55], [kut]

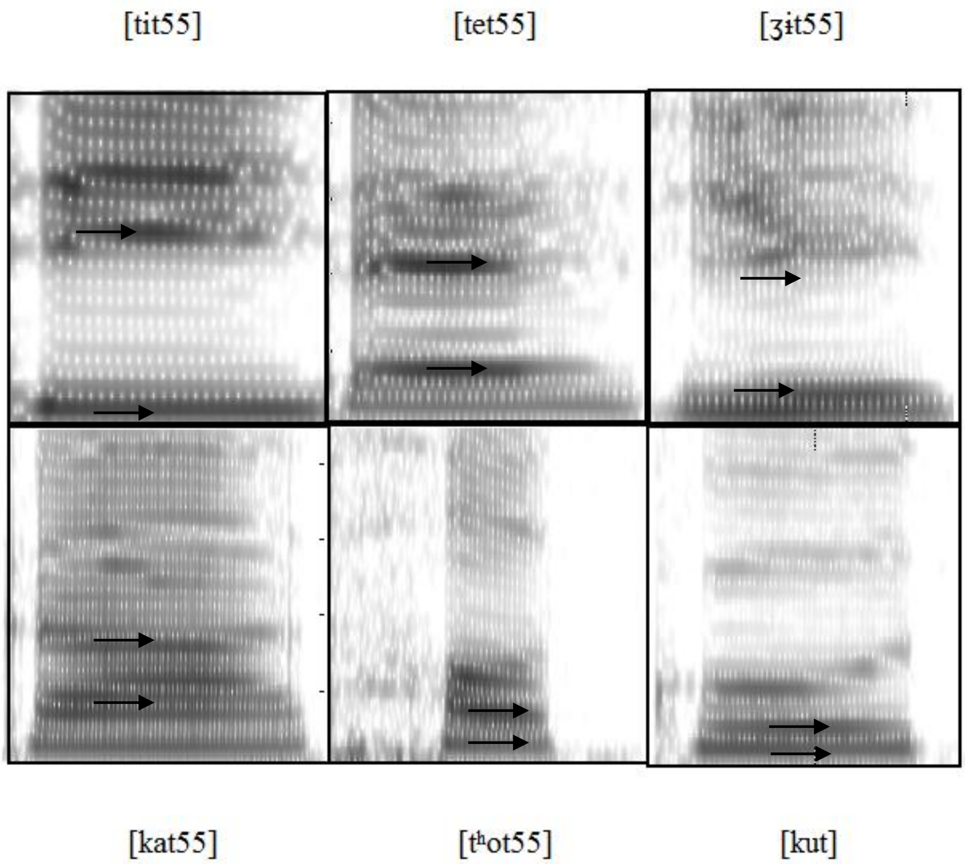


Figure 3.3 and Figure 3.4 show the spectrogram of six vowels of Hai-lu Hakka in CV and CVC structure. They are presented here because the acoustics of vowels can be visualized using spectrograms, which display the acoustic energy at each frequency, and how this changes with time. The arrows in each picture indicate the first and second formant of each monophthong. Besides the vowels, the release burst of the stop consonants [t], [t^h] and [k] can also be observed. In the right part of the spectrogram of [kut], the rising of the F2 format

can be observed, because the tongue position moves from the back vowel [u] to the alveolar stop [t].

4.3 Acoustic analysis of diphthongs

This section presents the acoustic analysis of eleven Hai-lu Hakka diphthongs [ie], [ia], [io] [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua]. To describe Hai-lu Hakka diphthongs precisely by acoustic approach, we design sixteen test words that place eleven diphthongs [ie], [ia], [io] [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua] in both CVV and CVVC structure. The sixteen test words are [nie31], [k^hia55], [k^hio55], [k^hiu55], [t^heu55], [p^hai55], [p^hau55], [t^hoi55], [k^hui55], [k^hua55], [tiet55], [t^hiap55], [kiok55], [k^hiuk55], [kuat55], and [kuet55].

4.3.1 Formant frequencies of diphthongs

This section gives the acoustic data analysis of the eleven diphthongs [ie], [ia], [io] [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua] by giving the mean F1 and F2 value of six subjects and their positions in a vowel space. The mean F1 and F2 values (Hz) of 11 diphthongs of Hai-lu Hakka in all subjects is presented in Table 3.2

Table 3.2 Mean F1 and F2 values (Hz) of 11 diphthongs of Hai-lu Hakka in all subjects

			Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Mean	SD
[ie]	[i]	F1	289.00	296.35	325.47	280.57	275.47	235.07	283.66	29.6
		F2	3066.21	2907.03	2912.18	2463.08	2490.17	2508.67	2724.57	266.5

	[e]	F1	553.95	510.36	567.13	495.87	461.19	502.00	515.08	39.2
		F2	2805.01	2792.47	2713.56	2460.22	2580.32	2459.47	2635.18	157.6
[ia]	[i]	F1	325.05	336.31	318.18	297.31	285.00	296.05	309.65	19.83
		F2	2806.35	3057.67	3098.48	2502.46	2515.00	2458.24	2739.70	289.92
	[a]	F1	1120.08	1086.35	1369.00	996.17	1020.54	985.13	1096.21	143.6
		F2	1821.00	1988.24	1965.31	1505.78	1540.23	1417.44	1706.5	249.4
[io]	[i]	F1	295.11	325.56	314.32	296.74	280.11	275.32	297.86	19.3
		F2	2885.75	3029.02	3028.22	2396.17	2535.08	2508.96	2730.53	283.16
	[o]	F1	602.85	596.66	587.12	565.23	571.67	562.24	580.96	17.0
		F2	1316.36	1300.11	1254.00	1166.17	1139.88	1017.09	1198.94	113.7
[iu]	[i]	F1	342.47	355.18	348.02	321.46	295.32	293.92	326.06	26.8
		F2	2966.21	2907.03	2812.18	2563.08	2490.17	2508.67	2707.89	212.3
	[u]	F1	421.57	426.91	438.65	387.00	399.98	385.42	409.92	22.2
		F2	1221.04	1204.28.96	1197.02	992.16	876.08	954.47	1074.18	150.9
[eu]	[e]	F1	621.57	632.67	598.33	611.00	593.91	594.17	608.61	16.0
		F2	2398.63	2491.98	2317.22	2106.00	2107.46	2029.63	2241.82	186.8
	[u]	F1	439.21	477.05	409.81	381.86	340.25	330.87	396.51	56.9
		F2	921.50	880.93	851.57	891.99	861.27	799.00	867.71	41.7
[ai]	[a]	F1	1312.58	1395.04	1068.31	1127.12	1084.77	977.38	1075.27	195.4
		F2	1880.22	1997.23	1876.50	1588.41	1400.95	1389.72	1688.84	264.3
	[i]	F1	345.77	327.04	315.03	289.95	290.66	287.11	309.26	24.0
		F2	2787.17	2701.81	2804.11	2512.06	2455.00	2568.54	2638.12	147.0
[au]	[a]	F1	1112.45	1000.33	1021.07	946.00	958.36	919.00	992.87	69.8
		F2	1785.22	1589.54	1505.27	1427.24	1468.64	1361.01	1461.23	79.7
	[u]	F1	719.09	893.01	769.14	553.99	429.37	608.67	662.21	165.7
		F2	979.00	1027.95	883.22	952.08	836.53	786.89	910.95	91.3
[oi]	[o]	F1	600.13	620.33	598.02	565.97	580.00	584.44	591.48	18.9
		F2	1335.41	1458.25	1257.36	994.02	1188.14	1002.55	1206.00	184.2
	[i]	F1	395.11	458.58	387.56	397.05	357.91	360.09	392.72	36.5
		F2	2600.64	2407.02	2278.09	2188.98	2200.00	2135.17	2301.65	174.2
[ui]	[u]	F1	419.00	388.46	467.33	403.77	407.12	397.28	413.87	28.1
		F2	880.01	871.56	800.76	782.32	757.97	767.00	809.97	53.1
	[i]	F1	310.64	315.74	334.00	297.35	278.00	299.15	305.81	19.0
		F2	2506.00	2471.99	2302.74	2000.05	2198.00	1998.84	2246.27	221.7
[ue]	[u]	F1	482.57	508.04	468.12	428.25	432.09	398.61	452.95	40.3
		F2	779.33	767.09	771.02	752.22	733.56	740.09	757.22	18.2
	[e]	F1	520.65	538.22	517.08	487.00	467.19	470.33	500.08	29.3

		F2	2530.19	2450.71	2477.01	2332.08	2127.49	2369.00	2381.91	144.7
[ua]	[u]	F1	539.53	546.31	518.61	473.00	469.06	489.77	506.05	33.5
		F2	744.14	779.53	770.88	698.99	732.05	720.30	740.98	30.5
	[a]	F1	1212.58	1007.59	1000.36	1018.32	945.17	888.03	1012.00	110.0
		F2	1685.00	1600.08	1674.74	1200.24	1358.76	1489.00	1501.30	191.2

Based on the mean F1 and F2 vlaue of the eleven diphthongs, we put each vowel in the vowel space. By comparing the relative position of the vowel in a diphthong and the corresponding vowel as in a monophthong as in Figure 3.2, we found that the second vowel in a diphthong tend to be higher or lower, more fontal or back, and it is possibly due to the coarticulatory influence of the adjacent phones.

Figure 3.5 The distribution of the mean F1 and F2 value of diphthongs [ie] and [ia] from six subjects in the vowel space

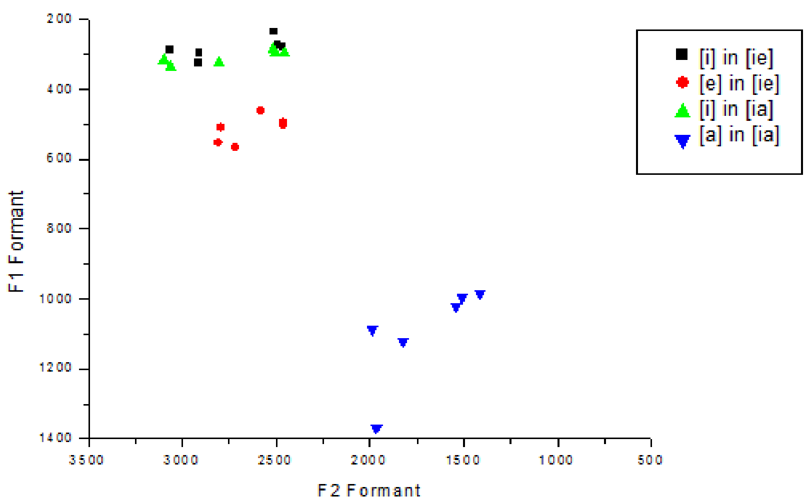


Figure 3.6 The mean F1 and F2 value of [i], [e], and [a] in diphthongs [ie] and [ia] from six subjects in the vowel space

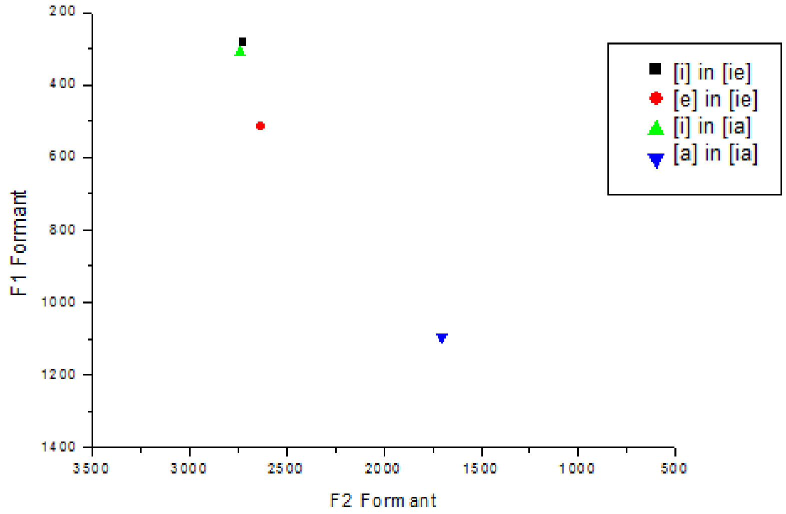


Figure 3.5 and Figure 3.6 show the vowel charts of diphthongs for [ie] and [ia]. Compared with the position in the vowel space of [e] and [a] in their corresponding monophthong as in Figure 3.2, the position of [e] and [a] is higher. This may result from the fact that the adjacent phone is a high front vowel [i].

Figure 3.7 The distribution of the mean F1 and F2 value of diphthongs [io] and [iu] from six subjects in the vowel space

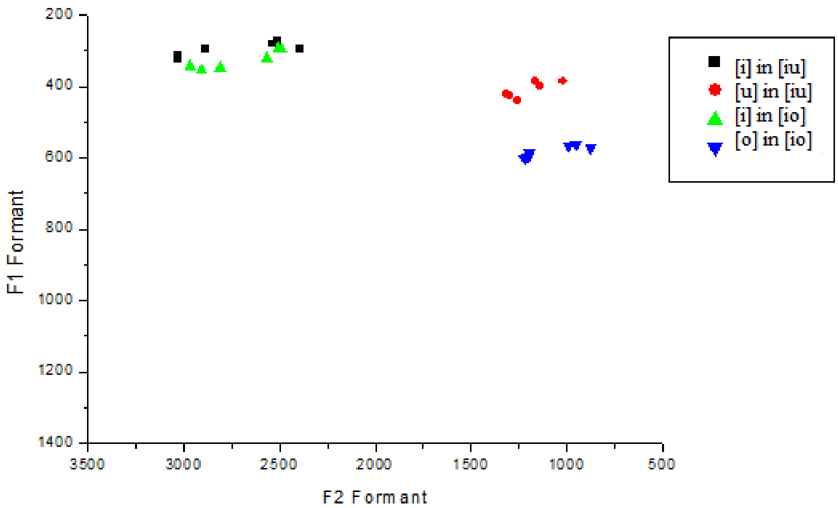


Figure 3.8 The mean F1 and F2 value of [i], [o], and [u] in diphthongs [io] and [iu] from six subjects in the vowel space

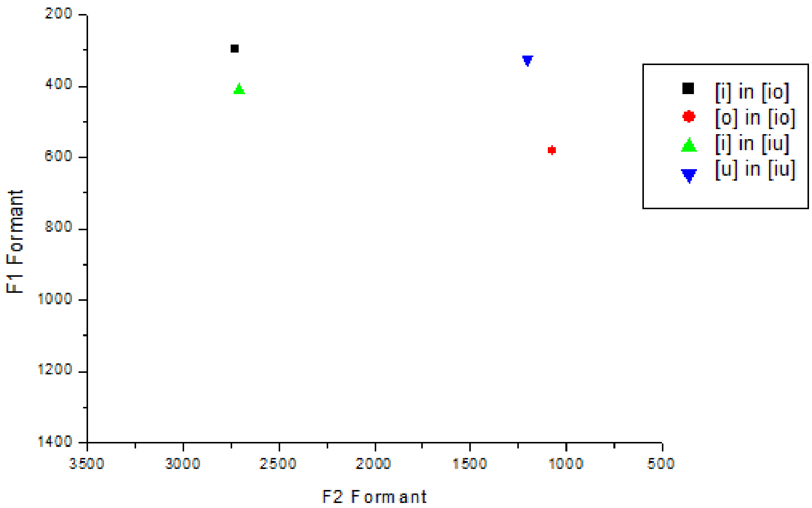


Figure 3.7 and Figure 3.8 show the vowel charts of diphthongs for [io] and [iu]. Compared with the position in the vowel space of [o] and [u] in their corresponding monophthong as in Figure 3.2, the position of [o] and [u] is more

frontal. This may result from the fact that the adjacent phone is a high front vowel [i].

Figure 3.9 The distribution of the mean F1 and F2 value of diphthongs [eu] from six subjects in the vowel space

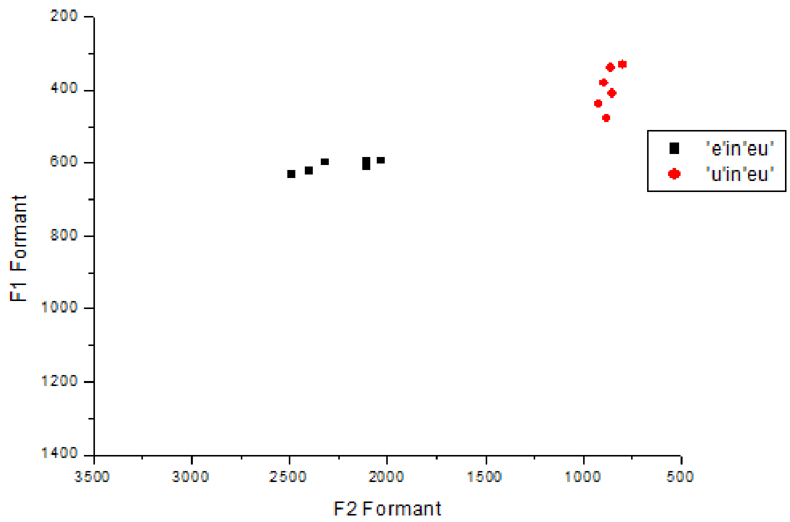


Figure 3.10 The mean F1 and F2 value of [e], and [u] in diphthongs [eu] from six subjects in the vowel space

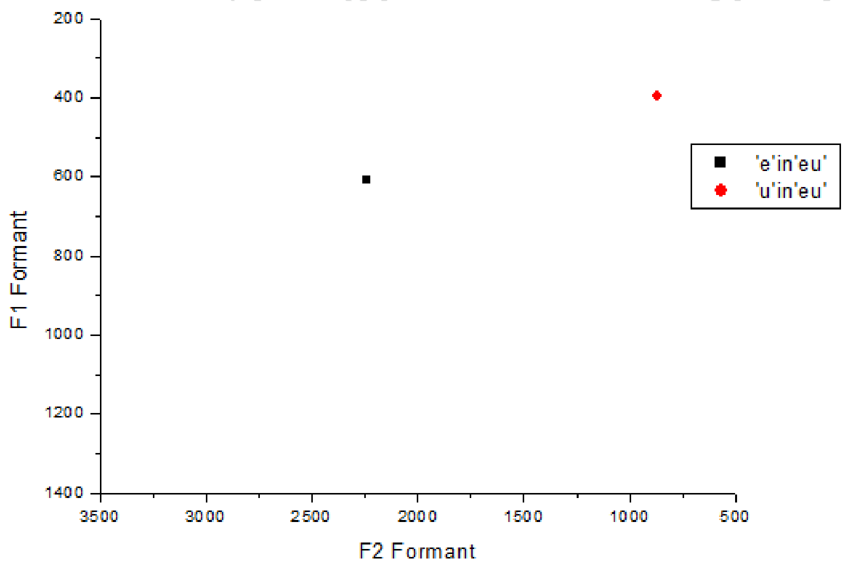


Figure 3.9 and Figure 3.10 show the vowel charts of diphthongs for [eu] Compared with the position in the vowel space of [e] and [u] in their corresponding monophthong as in Figure 3.2, the position of [u] is more frontal, and the position of [e] is more back. This may result from the fact that the adjacent phones affect each other.

Figure 3.11 The distribution of the mean F1 and F2 value of diphthongs [ai] and [au] from six subjects in the vowel space

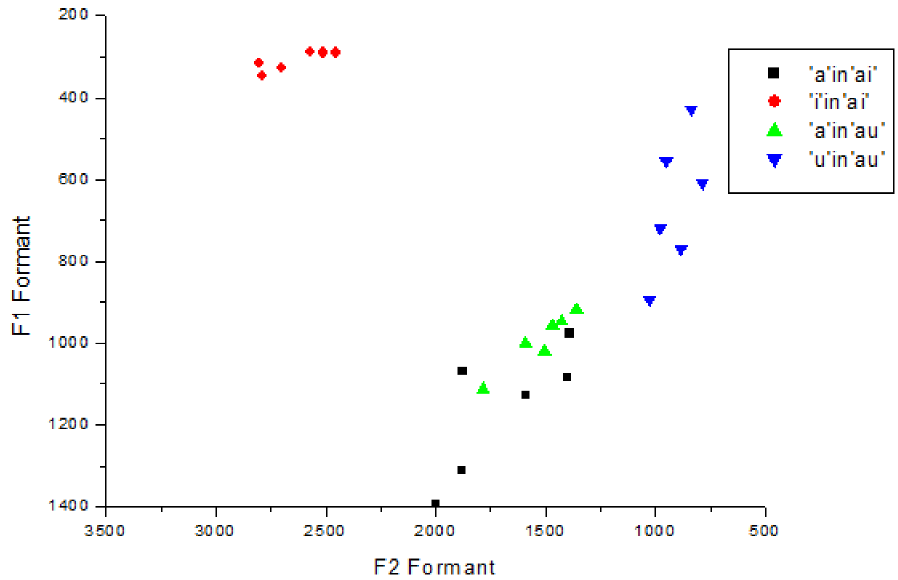


Figure 3.12 The mean F1 and F2 value of [a], [i], and [u] in diphthongs [ai] and [au] from six subjects in the vowel space

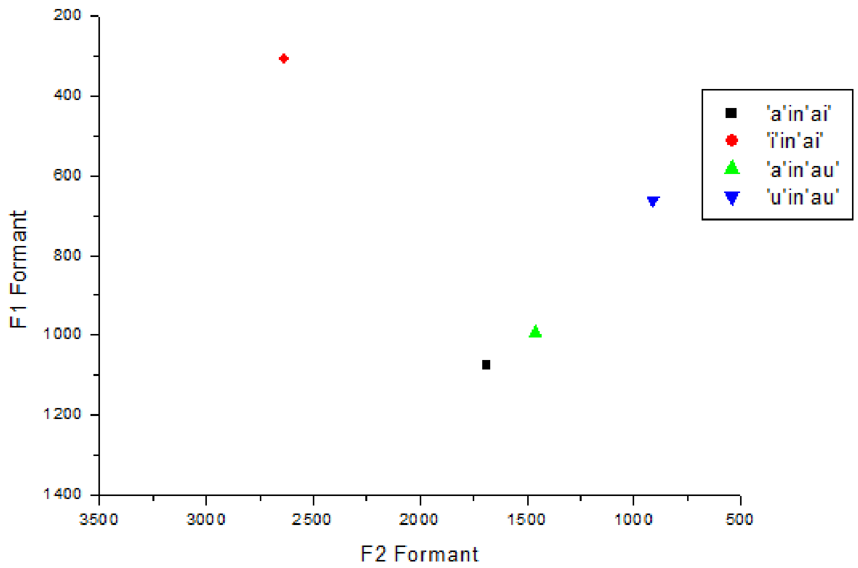


Figure 3.11 and Figure 3.12 show the vowel charts of diphthongs for [ai] and [au]. Compared with the position in the vowel space of [i] and [u] in their corresponding monophthong as in Figure 3.2, the position of [i] is lower, and the position of [u] is also lower. It is due to the influence of the adjacent low vowel [a].

Figure 3.13 The distribution of the mean F1 and F2 value of diphthongs [oi] from six subjects in the vowel space

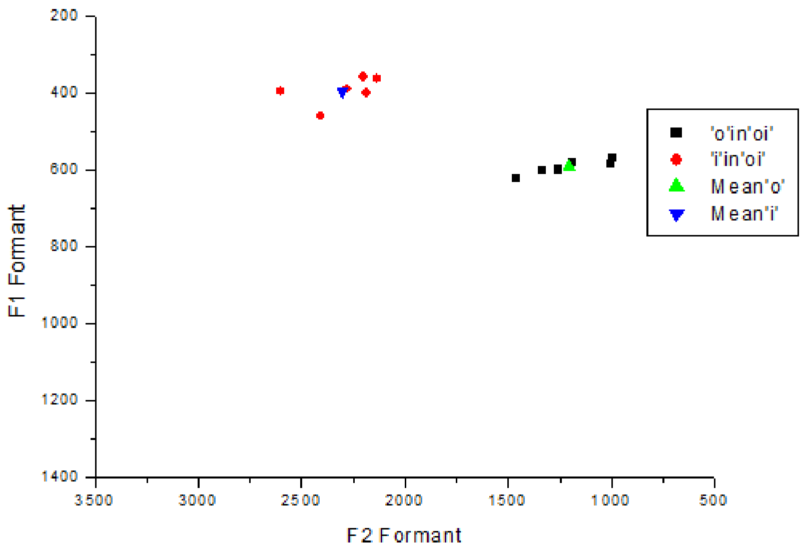


Figure 3.9 and Figure 3.10 show the vowel charts of diphthongs for [oi] Compared with the position in the vowel space of [o] and [i] in their corresponding monophthong as in Figure 3.2, the position of [o] is more frontal, and the position of [i] is more back. This may result from the fact that the adjacent phones affect each other.

Figure 3.14 The distribution of the mean F1 and F2 value of diphthongs [ui] and [ue], and [ua] from six subjects in the vowel space

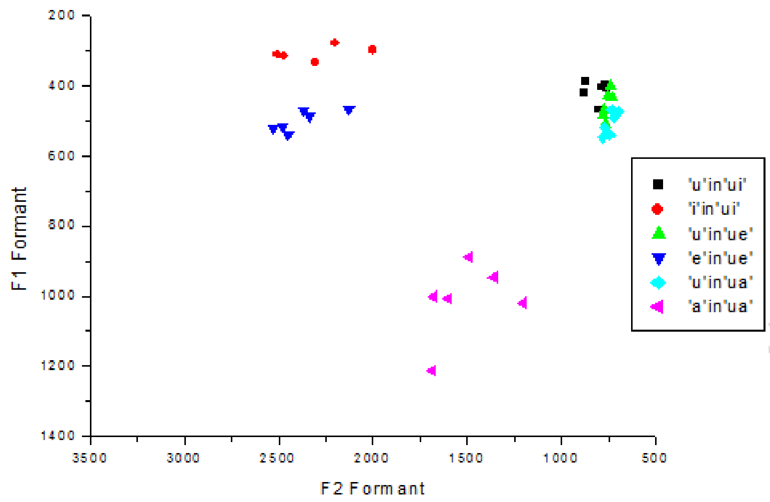


Figure 3.15 The mean F1 and F2 value of [u], [i], [e],and [a] in diphthongs [ui], [ue] and [ua] from six subjects in the vowel space

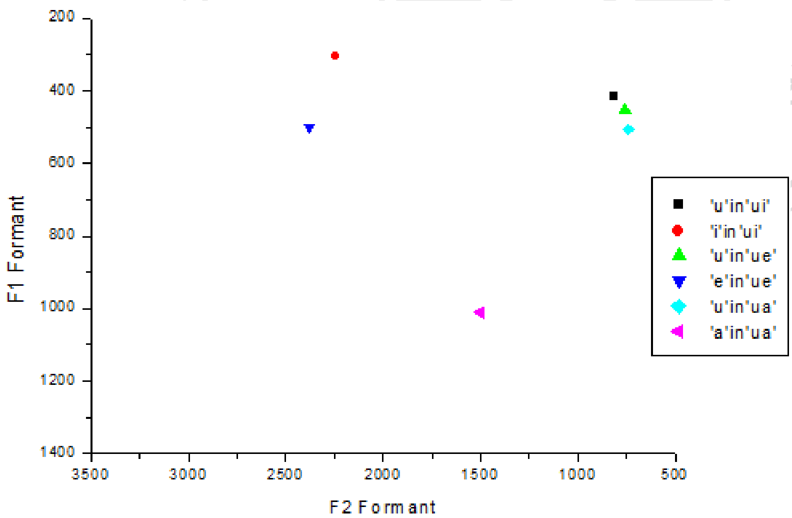


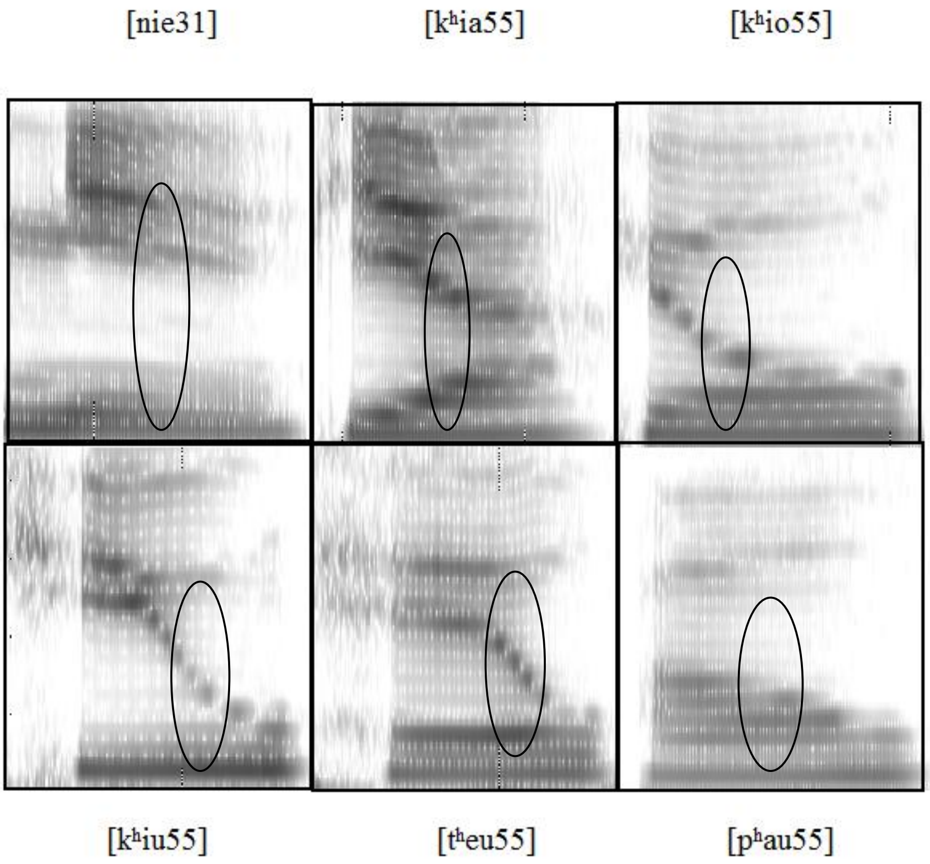
Figure 3.14 and Figure 3.15 show the vowel charts of diphthongs for [ui], [ue] and [ua]. Compared with the position in the vowel space of [i], [e] and [a] in their corresponding monophthongs as in Figure 3.2, the position of [i] and [e] is

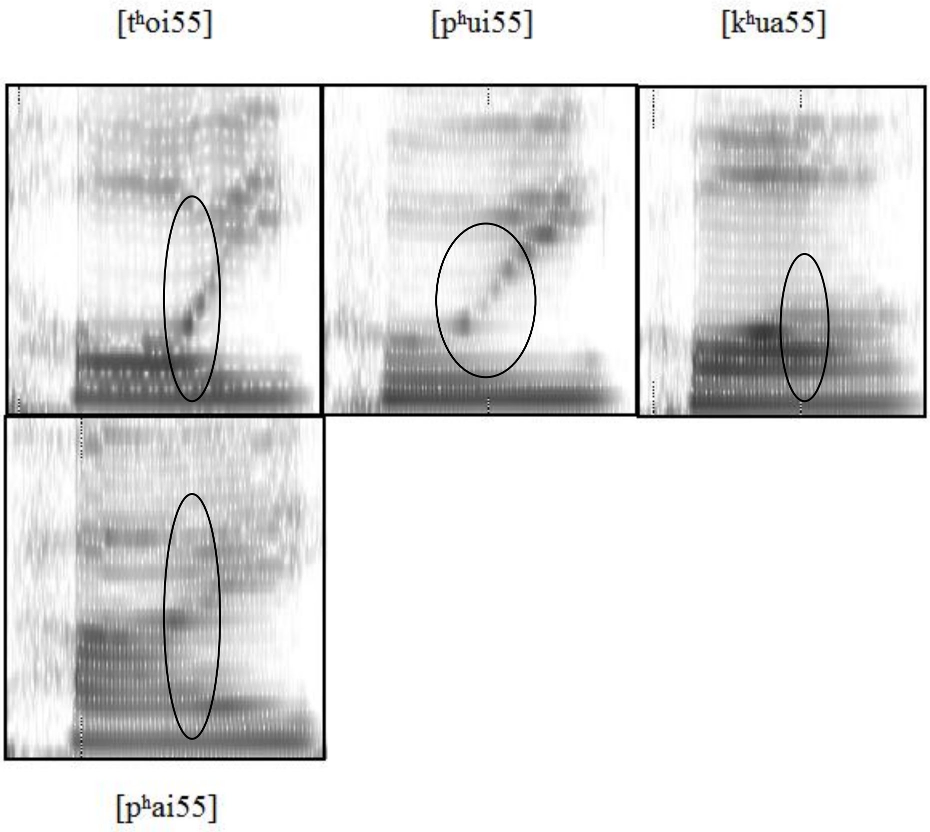
more back, and the position of [a] is higher. It is due to the influence of the adjacent high back vowel [u].

4.3.2 Spectrogram of diphthongs

This section presents how s eleven diphthongs [ie], [ia], [io] [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua] are presented as in a spectrogram. From all of the six subjects and 1086 reliable data, the spectrogram presented here are taken from one female speaker who is labeled as ‘subject 2’. To see the detailed description of the subjects, please see appendix I.

Figure 3.16 The spectrogram of CVV structure [nie31], [k^hia55], [k^hio55], [k^hiu55], [t^heu55], [p^hau55], [t^hoi55], [p^hui55], [k^hua55], and [p^hai55]





The spectrogram of CVV structure [nie31], [kʰia55], [kʰio55], [kʰiu55], [tʰeu55], [pʰau55], [tʰoi55], [kʰui55], [kʰua55], and [pʰai55] are presented in Figure 3.16, and the spectrogram of CVVC structure [tiet55], [tʰiap55], [kiok55], [kʰiuk55], [kuet55], and [kuat55] are presented in Figure 3.17.

As pointed by the circle, we can clearly identify each vowel-to-vowel transition in each spectrogram. Diphthongs can be characterized by clear vowel-to-vowel on the spectrogram.

Besides vowels, the release burst of the stop consonants [t], [tʰ], [k], and [kʰ] can also be observed on the left part of each spectrogram. The burst of bilabial [p] is fairly faint and scattered over a wide range. The burst of alveolar [t] is in the higher frequency range. The [k] burst has its greatest intensity between 2000 and 3000 Hz.

Figure 3.17 The spectrogram of CVVC structure [tiet55], [t^{h}iap55], [kiok55], [k^{h}iuk55], [kuet55], and [kuat55]

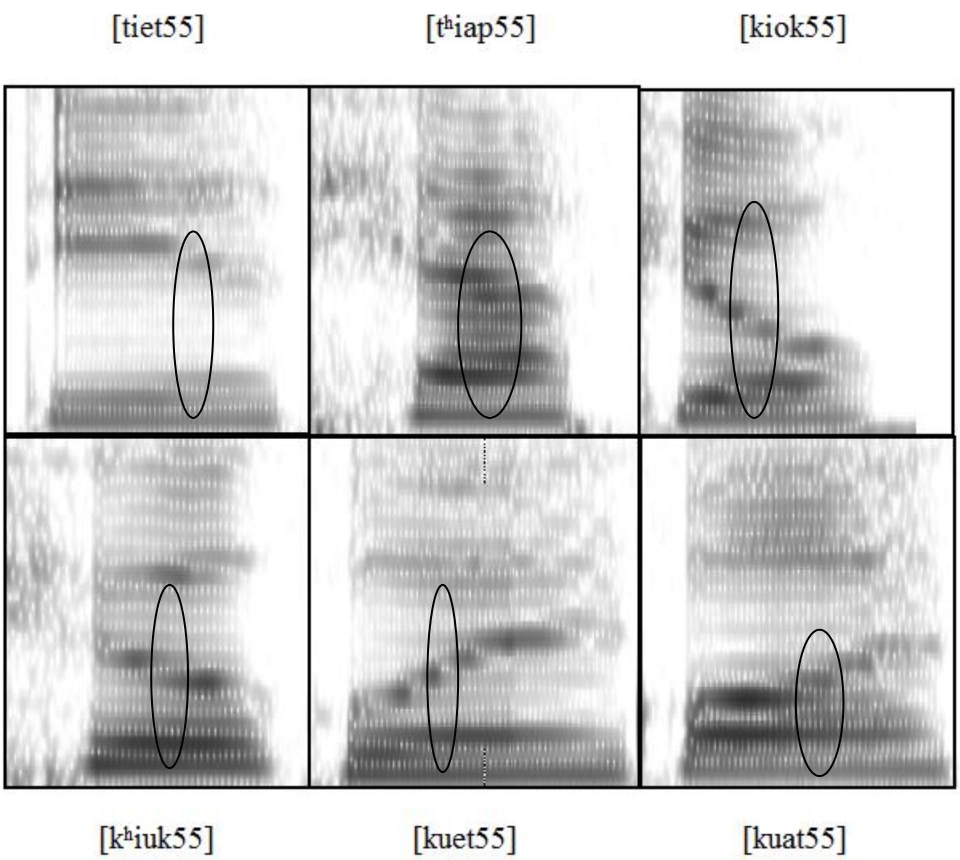


Figure 3.17 shows the spectrogram of diphthongs [ie], [ia], [io], [iu], [ue] and [ua] of Hai-lu Hakka in CVVC structure. On the left part of the spectrogram, there are small downward movements at the end of [t^{h}iap55], and very little movement at the end of [kuet55] and [kuat55]. There is a tendency that the second and third formants come together at the beginning of [kiok55] and [k^{h}iuk55].

As we can see from the spectrograph of the six test items [tiet55], [t^{h}iap55], [kiok55], [k^{h}iuk55], [kuet55], and [kuat55], the release burst of the stop consonants [t],

[t^h] and [k] can be observed. The burst of bilabial [p] is fairly faint and scattered over a wide range. The burst of alveolar [t] is in the higher frequency range. The [k] burst has its greatest intensity between 2000 and 3000 Hz.

As pointed by the circle, we can clearly identify each vowel-to-vowel transition in each spectrogram. In all of the six items, the transitions of the first and the second formant of the two vowels can be clearly observed. Diphthongs can be characterized by clear vowel-to-vowel on the spectrogram.

4.4 Acoustic analysis of tripthongs

This section presents the acoustic analysis of the three tripthongs [iai], [iau] and [uai]. To describe the location of three tripthongs [iai], [iau] and [uai] precisely by acoustic approach, we design three test words that place three tripthongs [iai], [iau] and [uai] in CVVV structure. The three test words are [iai55], [tiau55], and [kuai55].

The mean F1 and F2 values (Hz) of three tripthongs of Hai-lu Hakka in all subjects are presented in section 4.4.1, and the spectrogram analysis of three tripthongs is provided in section 4.4.2.

4.4.1 Formant frequencies of triphthongs

This section presents the acoustic analysis of six Hai-lu Hakka tripthongs [iai], [iau] and [uai]. Table 3.3 presents the mean F1 and F2 values (Hz) of three triphthongs of Hai-lu Hakka in all six subjects.

Table 3.3 Mean F1 and F2 values (Hz) of 4 triphthongs of Hai-lu Hakka in all subjects

			Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Mean	SD
[iai]	[i]	F1		301.02				268.16	284.59	23.2
		F2		2927.45				2745.14	2836.30	129
	[a]	F1		1475.28				1027.56	1251.42	316.6
		F2		1679.38				1580.01	1629.70	70.7
	[i]	F1		322.17				251.74	286.96	49.8
		F2		2604.69				2515.08	2559.89	63.4
[iau]	[i]	F1	334.04	325.13	310.00	309.31	295.00	295.05	311.42	15.8
		F2	2816.15	3047.47	3108.49	2602.46	2515.04	2459.24	2758.14	276.59
	[a]	F1	1120.12	1076.35	1288.93	1002.17	1030.55	964.00	1080.35	116.0
		F2	1831.55	1800.24	1991.11	1535.77	1480.23	1468.05	1684.49	219.0
	[u]	F1	499.91	511.56	529.15	412.65	379.01	368.91	450.20	71.5
		F2	777.02	778.16	762.01	702.99	651.36	627.94	716.58	66.0
[uai]	[u]	F1	517.29	533.17	512.02	486.00	477.01	490.16	502.60	21.6
		F2	761.05	778.87	751.33	702.27	715.00	716.31	737.47	30.5
	[a]	F1	1272.61	1286.55	1100.00	1002.12	1004.71	988.49	1109.08	138.0
		F2	1806.21	1800.00	1914.55	1233.11	1686.38	1221.77	1610.33	305.2
	[i]	F1	336.29	320.46	305.08	299.52	287.88	289.05	306.38	18.9
		F2	2601.33	2576.0	2503.19	2502.02	2344.41	2201.21	2454.70	153.1

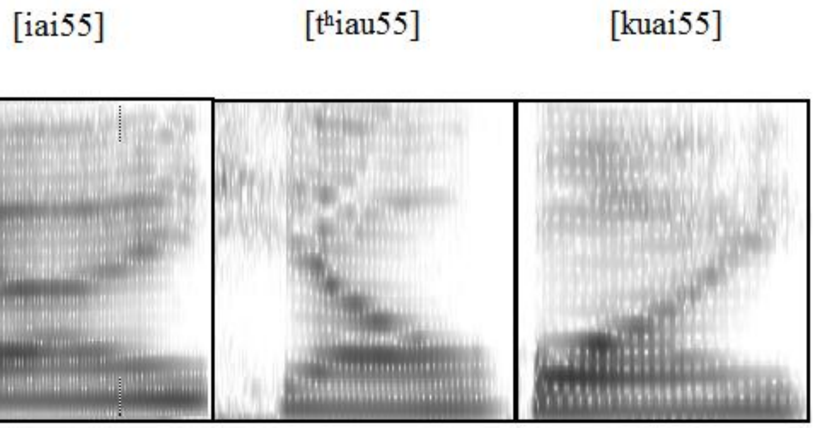
4.4.2 Spectrogram of triphthongs

The spectrogram of CVVV structure [iai55], [tiau55], and [kuai55] are presented in Figure 3.18. The test item [tsʰioi55] is not presented in this section because six of the subjects did not pronounce the sound we expected. Thus the three-vowel sequence [ioi] do not exist in Hai-lu Hakka under study.

The test word [iai55] can only be pronounced correctly by two of the six subjects, and the rest four subjects pronounce [ʒai55] instead. Based on my intuition, the recent change in [i] to [ʒ] has been undergone in many Hakka speakers.

As shown in the spectrogram, the duration of [i] in [iai55], [i] in [tʰiau55] and [u] in [kuai55] are relatively shorter than the rest two vowels in the same syllable, as [ai] in [iai55], [au] in [tʰiau55] and [ai] in [kuai55]. In these CVVV syllables, [u] and [i] are similar to glides or so-called semi-vowels, or approximants [j] and [w] as shown in the spectrogram. A glide [j] in the spectrograph is characterized by the lowering of the F1 formant and the visible rising of the F2 format, since glide [j] is like the high front vowel [i] but with shorter duration. The spectrogram of glide [w] is characterized by the lowering of the first and second formants, since glide [w] is like the high back rounded vowel [u] but with shorter duration.

Figure 3.18 The spectrogram of CVVV structure [iai55], [tʰiau55], and [kuai55]



4.5 Summary

In this chapter, we present the mean level of formant frequencies of the six Hai-lu Hakka monphthongs, eleven Hai-lu Hakka diphthongs and three Hai-lu Hakka triphthongs. from our 1086 acoustic analysis.

Compare the mean F1 and F2 value of three male subjects and three female subjects, we found that the overall formant frequency values of the vowels for the male speakers are lower than those for the female speakers. This result is due to the differences in vocal tract dimensions between male and female speakers.

With the mean F1 and F2 value, we present the distribution of six monophthongs [i], [e], [ɨ], [a], [o] and [u]in the vowel space in 4.2. The results confirm the application of the acoustic theory in accounting for English that the spectrogram analysis showed the acoustic feature of having lower F1 in high vowels and higher F1 in low vowels.

The distribution of eleven diphthongs [ie], [ia], [io] [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua] in a vowel space is provided in 4.3. Comparing their distribution with monophthongs, we found that the second vowel in a diphthong tend to be influenced a lot by the place of articulation of the first vowel. For example, compared with being a single vowel, when middle vowel [e] and low vowel [a] appear as the second vowel in [ie] and [ia], they tend to be higher in the vowel space. It is because of the coarticulatory influence of the adjacent phones : the high front vowel [i]. Similarly, compared with being a single vowel, when back vowel [u] appears as the second vowel in [iu], it tends to be more frontal in the vowel space.

CHAPTER V

CONCLUDING REMARKS

5.1 Summary of the findings

This study aims to investigate the vowel quality of Hai-lu vowels from an acoustic approach. We attempt to provide a survey on the formant frequencies of high vowel phones, low vowel phones, and mid vowel phones and their distribution in the vowel space. This thesis attempts to reply to the research questions with the findings of the acoustic data in Hai-lu Hakka.

Six subjects were recruited in this study, including three males and three females. From examining the acoustic data, some findings that related to the vowel quality of Hai-lu Hakka surface vowels are reported.

The overview of the data in this study presents the relative position of the six single vowels [i], [e], [ɨ], [a], [o], and [u] in vowel space. Furthermore, the results of this study confirm the application of the acoustic theory in accounting for English. For example, the spectrogram analysis showed the acoustic feature of having lower F1 in high vowels and higher F1 in low vowels.

To answer the first research question: How many single vowels are there in Hai-lu Hakka under study? According to the experiment and acoustic analysis, there are six monophthongs in Hai-lu Hakka, and this confirms the claims in Yang (1952), Lo (1990) and Chen (2000).

As for the second research question: How many diphthongs are there in Hai-lu Hakka under study? There are eleven diphthongs [ie], [ia], [io] [iu], [eu], [ai], [au], [oi], [ui], [ue], and [ua].

To answer the third research question: What are three vowels represented in the spectrogram? There are three diphthongs in the phonological system of Hai-lu Hakka vowels: [iai], [iau], and [uai]. As shown in the spectrogram, the duration of [i] in [iai55], [i] in [t^hiau55] and [u] in [kuai55] are relatively shorter than the other two vowels: [ai] in [iai55], [au] in [t^hiau55] and [u] in [kuai55]. In these CVVV syllables, [u] and [i] are similar to glides, or so-called semi-vowels [j] and [w] as shown in the spectrogram.

To Sum up, the vowel system in Yang (1957) is more suitable for accounting for the data in this study. Hopefully, the vowel formant data presented in this study will contribute to the study of vowels in Hakka.

5.2 Future research

There are two possible directions for further research in the future. One is the acoustic study that investigates the influence of initial and final consonant or the form of production on the vowel quality.

The other direction for future study is the sociolinguistic investigation into the sound change of Hakka. The sociolinguistic approach provides a more satisfactory explanation for the historic change of speech sound and the variation of a language. With the help of sociolinguistic knowledge, the motivation for the sound change, the social factors behind the language variation, and the possible influence from the mother tongue of Hai-lu speakers such as Taiwan Mandarin, Taiwanese Southern Min, and other local native languages would be further explored.

APPENDIX I

	Personal Data						Language Proficiency		
	Name	Gender	Birth Place	Living Place	Year of Birth	Age	Taiwan Mandarin	Taiwanese Southern Min	Others
Subject1	YQM	Female	Xinpu town, Hsinchu county	Xinpu town, Hsinchu county	1959	53	Fluent	Able to speak but not fluent	No
Subject2	YCM	Female	Xinpu town, Hsinchu county	Xinpu town, Hsinchu county	1957	55	Fluent	Able to speak but not fluent	No
Subject3	YLNM	Female	Xinpu town, Hsinchu county	Xinpu town, Hsinchu county	1937	75	Fluent	Fluent	No
Subject4	YHS	Male	Xinpu town, Hsinchu county	Xinpu town, Hsinchu county	1961	51	Fluent	Able to speak but not fluent	No
Subject5	LJY	Male	Xinpu town, Hsinchu county	Xinpu town, Hsinchu county	1957	55	Fluent	Able to speak but not fluent	No
Subject6	YSY	Male	Xinpu town, Hsinchu county	Xinpu town, Hsinchu county	1934	78	Fluent	Able to speak but not fluent	No

APPENDIX II

Monophthong	i	e	ɨ	a	o	u
CV	提[tʰi55]	乞 [kʰe55]	慈[tsʰɨ55]	卡[kʰa55]	舵[tʰo55]	屠[tʰu55]
CVC	滴[tit55]	得[tet55]	益[ʒɨt55]	呷[kat55]	脫 [tʰot55]	骨[kut]

Diphthong	ie	ia	io	iu	eu	ai
CVV	蟻 [nie31]	佢[kʰia55]	茄 [kʰio55]	求 [kʰiu55]	頭[tʰeu55]	排 [pʰai55]
CVVC	跌 [tiet55]	帖 [tʰiap55]	腳 [kiok55]	曲 [kʰiuk55]		
Diphthong	au	oi	ui	ue	ua	
CVV	袍 [pʰau55]	臺[tʰoi55]	蔡 [kʰui55]		呱 [kʰua55]	
CVVC				國 [kuet55]	刮 [kuat55]	

Triphthong	iai	iau	ioi	uai
CVVV	椰 [iai55]	條 [tʰiau55]	脆 [tsʰioi55]	乖 [kuai55]
CVVVC				

APPENDIX III

編號____

錄音時間____月____日____午________時

姓名___________

出生地：_____縣_____鎮

成長地：_____縣_____鎮

現今居住地：_______________

出生年次：民國_______年

第二語言口說能力：

	不會說	會說但不流利	普通	流利	非常流利
台灣華語	□	□	□	□	□
閩南語	□	□	□	□	□
英語	□	□	□	□	□
其它_______	□	□	□	□	□

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