Concentric: Studies in Linguistics
31.1 (June 2005): 21-45

Vowel Dispersion in Truku*

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This study investigated the dispersion of vowel space and vowel distance in Truku, and how these two factors interact with gender and stress. The participants were grouped into 5-vowel, 4-vowel, and 3-vowel categories, according to the number of vowels they perceived to be in their language. Acoustic analysis of the participants' production of 77 disyllabic words revealed that more discernable patterns could be attributed to the 5-vowel and 3-vowel groups, whereas the 4-vowel group exhibited fewer discernable patterns. Two versions of Dispersion Theory are used to interpret the observed differences between 5-vowel and 3-vowel groups in terms of both vowel space and vowel distance. Gender differences in the size of overall vowel space corroborated previous research. In addition, stress was found to influence vowel distribution with respect to overall space and distance between vowels.

Key words: Truku, dispersion of vowels, vowel space, vowel distance, gender, stress

1. Introduction

This study investigates vowel space and vowel distance in Truku, an endangered Austronesian language in Taiwan, and how these are influenced by the factors of gender and stress. Two versions of Dispersion Theory are used to interpret the observed differences. Dispersion Theory was originally proposed by Liljencrants and Lindblom (1972) as an acoustically-based method for determining the vowel space and vowel inventory of a language, and has been incorporated into phonology within the Optimality Theory framework. Flemming (2004), for example, stated that constraints on appearance and combination of vocalic features are designed to maximize the acoustic contrast between pairs of adjacent vowels in a language's inventory. On this view, phonological contrast is achieved by the competing interaction of the following three constraints: (i) maximize the acoustic distinctiveness of contrasts, (ii) minimize articulatory effort, and (iii) maximize the number of contrasts.

Both Adapative Dispersion Theory and the Flemming version of Dispersion Theory stipulate the need for maximizing the acoustic distinctiveness of contrasts

* An earlier version of this paper was presented at the 11th Annual Meeting of the Austronesian Formal Linguistics Association (AFLA) and appeared in *Proceedings of AFLA 11, ZAS, Berlin, Germany.* 45-58. The authors would like to express their thanks to the six informants, Cui-uan Li, Sue-jhu Lin, Chun-jhu Ciu, De-ming Chen, Jin-biao Jhou and Cheng Lian, for their participation and enthusiasm. (Truku informants have been thanked using their Mandarin names.) The authors would also like to take this opportunity to thank Chung-ping Cheng and Tanya Visceglia for their valuable suggestions and discussions. All remaining errors of commission or omission are our own.

between two items in an inventory. The current study provides unique data in Truku which is particularly suited to testing Dispersion Theory, because there are conflicting opinions as to the number of vowels in the Truku inventory. In the scant literature currently available, Truku is inconsistently claimed to contain three vowels (/i/, /u/ and /a/), four vowels (/i/, /u/, /o/ and /a/) or five vowels (/i/, /e/, /u/, /o/ and /a/), not including the schwa.[1] For example, Hu (2003) claims that the Truku inventory consists of the three vowels /i/, /u/ and /a/. The ALCD (Center for Aboriginal Languages Cultures Education, 2001) classifies Truku as having the four vowels /i/, /u/, /o/ and /a/. Li (1992) claims that all three dialects of Seediq have /i/, /u/, /o/ and /a/, whereas the occurrence of /e/ or /ɯ/ depends on regional variation.[2] Yang (1976) and Chang (2000) consider all dialects of Seediq to have a five-vowel system, consisting of /i/, /e/, /u/, /o/ and /a/.

Many native speakers of Truku also differ with respect to their perception of the number of vowels in its inventory. In the current study, three male and three female speakers produced 77 disyllabic words; the participants were divided into “5-vowel”, “3-vowel” and “4-vowel” groups, according to the number of vowels they perceived to be in their language. We observed that [i], [u] and [a] were the distinctive vowels upon which all the participants in our study agreed, unlike [e] and [o]. For example, the front vowel /i/ in the word *mirit* ‘goat’ was consistently categorized as [i] by all of the participants, while the word ‘awake’ was categorized differently by the 5-vowel speakers as *meyaw*, by the 3-vowel and the 4-vowel speakers as *miyaw.* Similarly, the categorization of the vowel /u/ was consistent among all-type vowel speakers in the words such as *bunga* ‘sweet potato,’ but was inconsistent in words such as *buyak/boyak* ‘boar. ’ The 5-vowel and the 4-vowel speakers considered ‘boar’ to be *boyak* while the 3-vowel speakers considered it to be *buyak*. The ambiguous vowels can occur in the same phonetic contexts, so we do not consider them to be in complementary distribution. We do not believe that they occur in free variation, either, because our speakers did not regard them as interchangeable.

To facilitate the illustration and explanation of the data in this paper, [e] and [o] were represented by the alternating use of capital “I” and “E” for the former, and “U” and “O” for the latter. Capital letters represent the underlying form as recognized by different groups of speakers. For those words which contain inconsistent categorization of front non-low vowels among speakers, [E] represents the underlying [e] for the 5-vowel speakers, while [I] represents the underlying [i] for the 3-vowel and the 4-vowel speakers. Similarly, for those words that were inconsistently

[1] For the sake of clarity, we exclude the schwa in the vowel counts presented in this study. However, since the schwa is also a phoneme in Truku, the maximal number of vowel phonemes in Truku is six.

[2] Li chose /e/ to represent the fifth vowel, for the purpose of creating symmetry in the vowel inventory.

categorized as containing back non-low vowels, [O] represents the underlying [o] for the 5-vowel and the 4-vowel speakers, while [U] represents the underlying [u] for the 3-vowel speakers.

The current study investigates two research questions: (1) whether Dispersion Theory can account for variations in the reported number of Truku vowels with respect to vowel space and vowel distance; and (2) how the factors of gender and syllabic stress may interact with Truku vowels' distribution and contrastiveness.

The remainder of this paper will be organized in the following way: Section 2.1 will present background information about the phonological system of Truku, including its phonemic inventory, lexical stress, syllabic structure and phonotactic constraints. Section 2.2 will present theoretical considerations and our hypotheses. Section 3 will describe our participants, the experimental materials, procedure and acoustic measurements. Section 4 will present our results and Section 5 will discuss them in terms of the two versions of Dispersion Theory, as well as in terms of the interaction of gender and stress. Finally, Section 6 will conclude the paper and suggest directions for future study.

2. Background and theoretical considerations

2.1 Truku phonology

In terms of linguistic typology, Truku is classified as a descendant of proto-Atayal. Due to its long alienation from Atayal, Truku diverges considerably from its prototype. The Atayal tribe can be divided into two subtypes: Atayal and Seediq (Li *et al*., 1963 and Hung, 1993). The latter, further divided into three dialects, Teuda, Tkdaya and Truku, are spread throughout Taiwan's Nantou and Hualien counties. The current Truku-speaking population is 7844. Truku has no writing system, which is common to all Formosan aboriginal languages, so evidence of diachronic change cannot be determined from written records.

The number of vowel phonemes in Truku, as mentioned before, is controversial for both native speakers and researchers. Aside from its monophthongs, there are three diphthongs: /ay/, /au/ and /uy/, and seventeen consonants in Truku: /p/, /b/, /m/, /t/, /d/, /s/, /n/, /l/, flap /r/, /k/, /g/, /x/, /ŋ/(ng), /q/, /h/, /w/, and /y/.

According to Hu (2003), Truku vowels may have allophonic variation under certain conditions. For example, there may be transition vowels [ə] and [e] before the high front vowel [i] when it is adjacent to /q/ and /h/. Likewise, the high back vowel /u/ may be lowered when preceded or followed by /q/, /h/, and /ŋ/. The schwa /ə/ occurs only in the penultimate syllable.

Hu (2003) claims that CV(C) is the most prevalent syllable structure, and that possible syllable structures for Truku are: CV(N)…C**V**(C). (C)V(C)#. Lexical stress in Truku invariably falls on the penultimate syllable (Chang 2000, Hu 2003). Chang (2000) described this stress rule as:

V→ **V(stressed)**/__ (C)V(C)#

This rule can be applied even at the morphological level, since morphological change does not affect stress assignment.

2.2 Theoretical considerations

Adaptive Dispersion (Liljencrants and Lindblom, 1972; Lindblom, 1986, 1990) proposes that the distinctive sounds of a language tend to be positioned in phonetic space in a way that maximizes perceptual contrast. Contrast is created by increasing the distance between the point vowels in proportion to the size of a language's vowel inventory. As a result, languages with large vowel inventories tend to expand the overall acoustic vowel space.

Flemming (1995, 1996, 2004) introduced another version of Dispersion Theory, which incorporates the mechanisms of dispersion into current Optimality Theoretic (OT) constraints on phonological inventory development. Expressed in terms of OT, this version of Dispersion Theory claims that constraints favoring less perceptually confusable contrasts are ranked higher than constraints that would favor more easily confusable contrasts. Thus, the markedness of a sound would depend on the sounds that it contrasts with in a particular inventory. Although Adaptive Dispersion Theory and Flemming's Dispersion Theory resemble each other in terms of the goal of maximizing perceptual contrast, Flemming's distinctiveness of contrasts also claims that three functional goals may come into conflict. These goals are: (i) maximizing the distinctiveness of contrasts, (ii) minimizing articulatory effort, and (iii) maximizing the number of contrasts in a language's inventory. For example, the goal of maximizing the number of contrasts conflicts inherently with maximizing the distinctiveness of contrasts. If an inventory with two sounds is compared with a four-sound inventory, the former shows the maximal distinctiveness of two sounds, while the latter shows less distinctiveness between two sounds, but with a greater number of contrasts. So, the overall vowel space of a language with a larger vowel inventory may not necessarily be larger than that of a language with a smaller number of vowels. For example, if a 3-vowel system prioritizes the maximization of contrasts, while a 5-vowel system prioritizes the minimization of articulatory effort, the 3-vowel system might exhibit an even larger space than the 5-vowel system does.

Flemming extends the principle of maximizing perceptual contrast to explain the phenomenon of vowel neutralization in unstressed syllables. On this view, contrasts are difficult to produce in unstressed positions because the duration of unstressed syllables is reduced. This is especially true for low vowels: short low vowels are raised, which shortens the range of the F1 dimension used to distinguish F1 contrasts. Languages such as Greek (Fourakis *et al*., 1999) and American English (Fourakis 1991) exhibit general shrinkage of the vowel space in unstressed conditions.

As for gender differences in vowel articulation, it has been generally accepted that men and women produce different formant values due to differences in their oral-to-pharyngeal cavity length (Peterson and Barney 1952, Fant 1960). Female speakers will have larger F1 $\times$ F2 space due to relatively higher open vowel formants. The larger vowel dispersion that has been observed in women has been hypothesized to be the result of overall higher fundamental frequency (Cleveland 1977, Ryalls and Lieberman 1982), and socialization (Goldstein 1980).

This study tests the predictions of Dispersion Theory for the three different vowel systems reported by native Truku speakers. Using Adaptive Dispersion Theory (Liljencrants and Lindblom 1972, Lindblom 1986, 1990) and Flemming's version of Dispersion Theory, both of which claim that vowel distance needs to be maximized to create two different levels of vowel height, we make the following predictions: first, we predict that the overall vowel space would be larger for the 5-vowel system ([i], [E], [a], [u] and [O]) than for the 3-vowel system ([i], [a], [u]). As for the 4-vowel system, the overall vowel space would be in-between that of the 5-vowel and 3-vowel inventories. If not, Flemming's alternative version of Dispersion Theory will be employed to investigate possible conflicts in functional goals.

As for vowel distance, we predict that the distance between [i] and [E] for 5-vowel speakers will be relatively larger than that between [i] and [I] for the 3-vowel and the 4-vowel speakers, since the distance of [i] and [I] is likely to be too small to form two distinctive levels of vowel height. The vowel distance between the back vowels [u] and [O] in the 5-vowel system is also predicted to be relatively larger than the vowel distance between [i] and [I] in the 3-vowel system. As for the 4-vowel system ([i], [a], [u] and [o]), we predict that the distance between [i] and [I] will approximate that of the 3-vowel system, whereas the distance between [u] and [O] would approximate that of the 5-vowel system.

Moreover, we predict that gender and stress will also affect vowel dispersion; i.e., both women's vowel space and unstressed vowel space will be more widely dispersed. The overall vowel space is predicted to be reduced in unstressed conditions.

3. Method

3.1 Speakers

Three male and three female native speakers of Truku participated in this experiment. The participants were divided into "5-vowel", "3-vowel" and "4-vowel" groups, according to the number of vowels they perceived to be in their language; each group included one male and one female speaker. The 5-vowel group perceived the vowels [i], [e], [a], [u] and [o] in Truku, while the 3-vowel group perceived [i], [u] and [a]. The speakers in the 4-vowel group perceived [i], [u], [o] and [a]. Experimental materials designed for the 5-vowel group included [i], [E], [a], [u] and [O]; for the 3-vowel group: [i], [I], [a], [u] and [U]; and for the 4-vowel group: [i], [I], [u] and [O]. The details of the experimental designs will be elaborated in the Section 3. 2.

All of the speakers lived in Hualian county, where they spoke Truku daily, before moving to Taipei, at the age of twenty or above.[3] Their ages range from forty-two to forty-eight. All of them speak Mandarin to communicate with non-Truku speakers. Even though they have all lived in Taipei for approximately twenty years, they continue to visit Hualian often and frequently communicate with their tribespeople in Truku.

3.2 Materials

A list of seventy-seven disyllabic words containing the vowels [i], [I]/[E], [u] and [U]/[O] were selected from our field recordings. [I/E] and [U/O] sets consisted of words that were aimed to illicit inconsistent categorization of the vowels. Forty-four were presented in stressed conditions and thirty-three in unstressed conditions. The wordlist, including vowel occurrence tabulations, are given in Table 1. The words were selected specifically to include as many contexts as possible, in order to expand the number of conditions in which that word could appear. Gaps in this list result from either the lack of lexical item to fulfill that condition, or the absence of an acceptable token of such an item in the field recordings.[4] Forty disyllabic words

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[3] The 5-vowel male and female speakers come from Wan-rong and Siu-lin, respectively; the 4-vowel male speaker comes from Wan-rong and the female speaker comes from Siu-lin and both the 3-vowel male and female speakers come from Siu-lin (all place names in Tongyong Romanization).

[4] Yang (1976) and Chang (2000) both indicated a pair of phonological rules in Seediq in which the diphthongs [aw] and [ay] are the proto-form of [o] and [e]:

aw → o / __#   ay → e / __#

Our observation showed that Truku preserved these two diphthongs in a consistent way compared with Seediq. This may account for the sparse occurrence of unstressed [e] and [o] word-finally in containing the vowels [a] and [W] were added to test the integrity of the vowel chart, as given in (1c). The column of unstressed [W] in Table 1c is empty; our consultations with informants yielded no example in which [W] can appear as the second syllable of a disyllabic word.

our wordlist:
sinaw “wine” (Truku) > *sino* “wine” (Seediq)
walay “thread” (Truku) > *wale* “thread” (Seediq)

Table 1. a. Items representing *stressed* vowels in Truku

Preceding Consonants	[i]		[I]/[E]		[u]		[U]/[O]	
p	*pila*	‘money’	*pidang/ pedang*	‘[name]’	*pungu*	‘knee’	*puli/ poli’*	‘[name]
b	*birat*	‘ear’			*bunga*	‘sweet-potato’	*buyak/ boyak*	‘boar’
m	*mirit*	‘goat’	*miyaw/ meyaw*	‘awake’	*muhing*	‘nose’	*moda/ moda*	‘to pass’
t	*tɕimu*	‘salt’	*timu/ temu*	‘[name]’	*tunux*	‘head’		
d							*duhung/ dohong*	‘mortar’
n	*nisu*	‘your’			*nunuh*	‘a fig’	*nuxay/ noxay*	‘because’
k	*kingal*	‘one’			*kumay*	‘bear’		
g	*gimi*	‘to find’			*gupun*	‘teeth’	*gumuk/ gomuk*	‘a lid’
ng	*ngiraw*	‘mushroom’			*ngudus*	‘beard’		
q					*quyu*	‘snake’	*qumi/ qomi*	‘needle’
r	*risaw*	‘boy’	*rima/ rema*	‘five’			*rudux/ rodox*	‘chicken’
l	*lingis*	‘to cry’			*lungaw*	‘bottle’	*lumun/ lomun*	‘liver’
y			*yiku/ yeku*	‘[name]’	*yumaw*	‘[name]’	*yuna/ yona*	‘[name]’
w	*wihe*	‘spoon’						
h	*hiya*	‘he’	*hini/ heni*	‘here’			*huling/ holing*	‘dog’
s	*ɕida*	‘branch’			*sudu*	‘grass’	*suki/ soki*	‘knife’
z	*zima*	‘bamboo’						
Total	**14**		**6**		**12**		**12**	

Table 1. b. Items representing *unstressed* vowels in Truku

Preceding Consonants	**[i]**		**[I]/[E]**		**[u]**		**[U]/[O]**	
p	*rapit*	‘flying squirrel’			*gupun*	‘teeth’		
b	*labis*	‘mosquito’			*bubu*	‘mother’		
m	*qomi*	‘needle’			*lomun*	‘liver’		
t					*utux*	‘ghost’		
d					*sudu*	‘grass’		
n	*heni*	‘here’			*munuh*	‘to breast-feed’		
k	*daking*	‘to grow up’			*yaku*	‘I’		
g	*ləgi’*	‘to shake			*megun*	‘to tie’		
ng	*dangi*	‘lover’			*pungu*	‘knee’		
q			*laqe*	‘child’	*uqun*	‘sth to eat’		
r	*mirit*	‘goat’			*paru*	‘big’	*tWro*	‘three’
l	*holing*	‘dog’			*malu*	‘good’		
y					*quyu*	‘snake’		
w	*tCiwin*	‘little’						
h	*muhing*	‘nose’	*wihe*	‘spoon’			*dohong*	‘mortar’
x	*ləxi*	‘bamboo shoot’			*kuxul*	‘to like’		
s	*nasi*	‘if’			*nisu*	‘your’		
z	*buzi*	‘arrow’						
Total	**14**		**2**		**15**		**2**	

Table 1. c. Items containing the vowels [a] and [Ɯ] in Truku

Preceding Consonants	Stressed [a]		Stressed [Ɯ]		Unstressed [a]	
p	*paru*	'big'			*sapah*	'house'
b	*baraw*	'upper'			*yabas*	'guava'
m	*maxal*	'ten'	*mƜkan*	'to eat'	*tama*	'father'
t	*tama*	'father'	*tƜro*	'three'	*watan*	'[name]'
d	*daha*	'two'	*dƜmux*	'grains of'	*idas*	'moon'
n	*naku*	'my'			*kana*	'all'
k	*kari*	'language'	*kƜa*	'to understand'		
g	*gaga*	'that'	*gƜhak*	'seed'	*baga*	'hand'
ng	*ngali*	'to take'			*bunga*	'sweet-potato'
q	*qalux*	'balck'	*qƜpi*	'to squeeze'	*niqan*	'to own'
r	*rawa*	'basket'				
l	*laqe*	'child'	*lƜxi*	'bamboo shoot'	*alang*	'village'
y	*yamu*	'you (pl)'			*sayang*	'now; today'
w	*wadu*	'honey'			*rawa*	'basket'
h	*habuk*	'weast belt'	*hƜngak*	'air'	*daha*	'two'
x					*maxal*	'ten'
s	*sari*	'taro'	*sƜpac*	'four'	*mƜsa*	'this way'
Total	**16**		**9**		**15**	

3.3 Recordings

Recording sessions consisted of two parts. The first familiarized the informants with the items on a randomized list of words; the second directed the informants to pronounce each word once in Truku after hearing the corresponding Mandarin gloss. Some items contained two experimental vowels; these appeared twice in the wordlist, but never adjacently. The recordings were conducted in quiet rooms using a Sony TCM 5000-EV portable tape recorder and an electric condenser microphone which was located approximately 20 centimeters away from the informants' mouths.

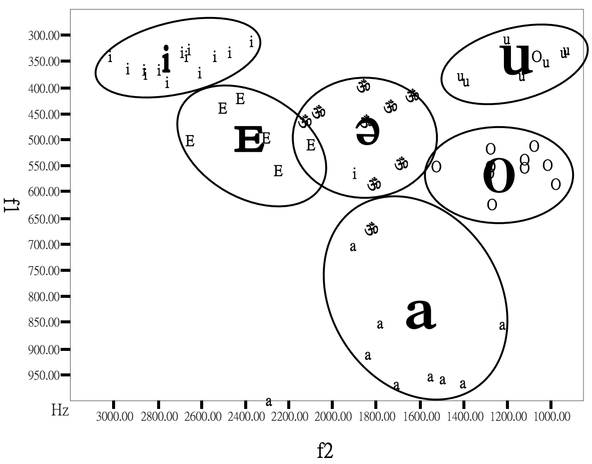
3.4 Measurements

The signals were later transferred to the Kay Elemetrics Computerized Speech Lab (CSL) in National Taiwan University's Phonetics Laboratory, using a 10-kHz sampling rate. Each word was displayed on a wideband spectrogram with a formant history, using a 300 kHz bandwidth cutoff. Using both visual and auditory cues, we removed the preceding and following consonantal transitions around the experimental vowel, so that only the steady state of each vowel remained. Then, five points within this stable range were extracted at equal distances: 0%, 25%, 50%, 75% and 100% of the steady-state duration. F1 and F2 values were obtained for each of these points by means of an LPC analysis. However, since the vowels [e] and [o] are often diphthongized, only the portion before their offglide was extracted. If formant values were unavailable for any of the default five points (0%, 25%, 50%, 75% and 100%), the value of an adjacent point was adopted, which was determined by examination of the LPC formant history.

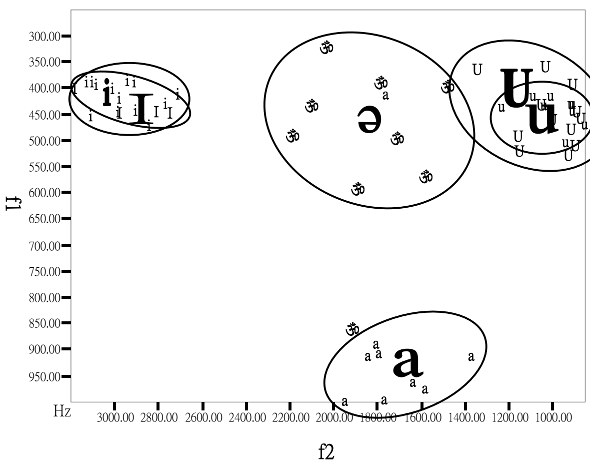
4. Results

The following sections will present vowel distribution across groups in terms of the factors vowel identity and gender, as produced in the stressed condition. First, Figures 1.a to 1.f show the vowel distribution of each speaker in the stressed condition. F1/F2 plots reveal that except for the 5-vowel female speaker (Figures 1.a), who has clear distinctions for all the vowels, the other speakers show overlap among vowels. This is especially apparent in Figure 1.b; for the 3-vowel female speaker, the controversial and non-controversial vowels occupy almost the same space. Furthermore, the male speakers' overall vowel space appears to be articulated further back than the female speakers'.

a. 5V-F's vowel distribution



b. 3V-F's vowel distribution



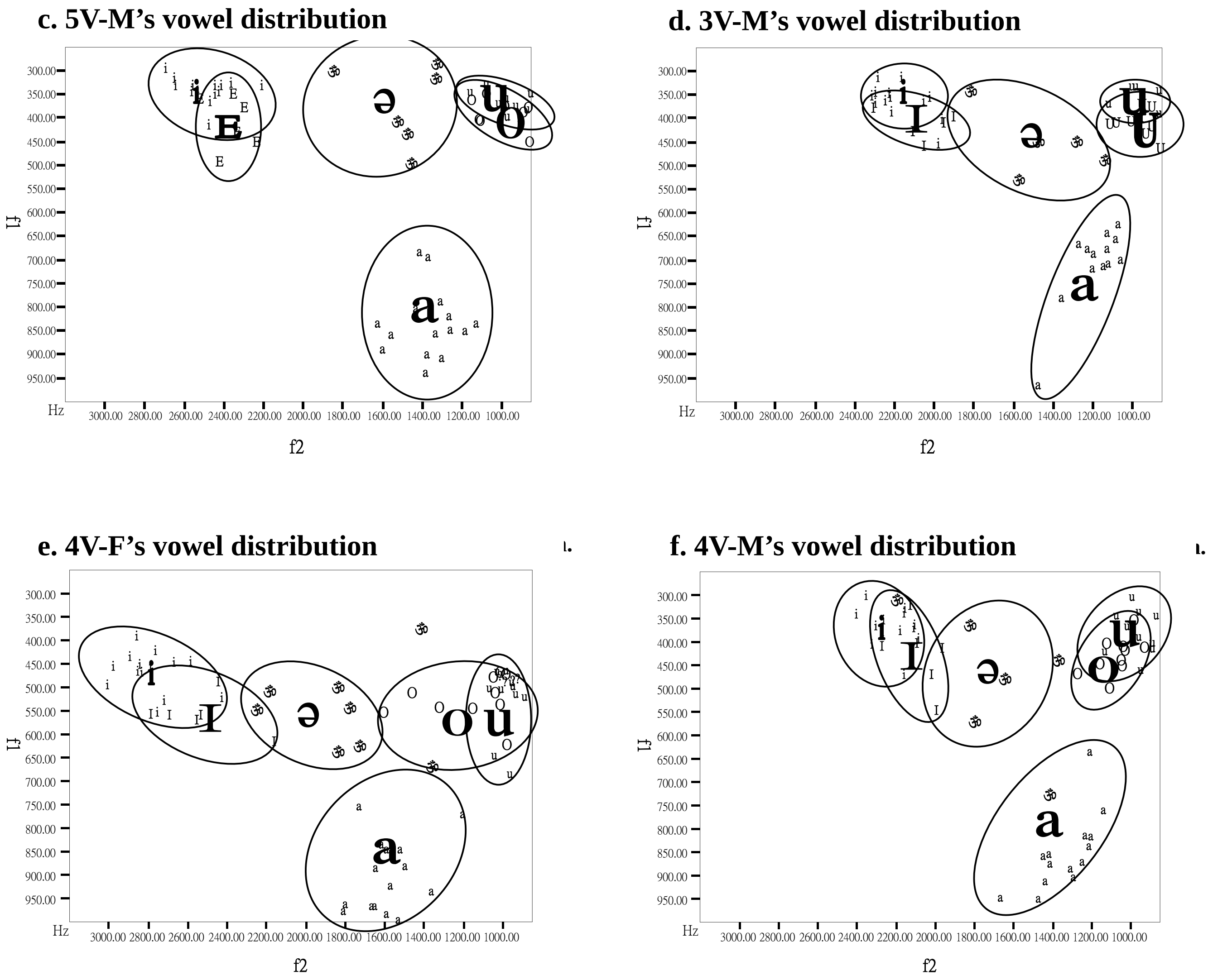


Figure 1. The six speakers' individual vowel distributions in the stressed condition

4.1 Front vowels: [i] vs. [I/E]

The data were analyzed using a MANOVA with factors Vowel, Gender, and Stress. Observed differences between stressed and unstressed conditions will be discussed in a later section. With the F1 and F2 values as the dependent variable, there were significant effects for both Vowel and Gender factors. (For [i]-[I/E] difference: $F(1, 1051) = 146.2$, $p < .01$; for female/male difference: $F(1, 1051) = 653.2$, $p < .01$). That is to say, the non-controversial [i] differs from the controversial [I/E] with respect to both F1 and F2 values despite the individual differences in perception. On the other hand, the factor of Gender is also significant for front vowels. The females' articulation of front vowels is lower and more fronted than the males'.

We will now turn to the aspect of within-subject variation in comparing [i] and [I/E]. Table 2 provides the formant values and the ANOVA results for the comparison of the two front vowels [i] and [I/E].

Table 2. Formant values (Mean/SD) of the front vowels

Mean (SD): Hz		[i]	[I/E]	ANOVA
5V-Female	F1	364 (61)	486 (51)	F(1, 98) = 61. 53, $p < .001$
	F2	2649 (280)	2371 (196)	F(1, 98) = 22. 04, $p < .001$
4V-Female	F1	464 (44)	556 (41)	F(1, 98) = 66. 11, $p < .001$
	F2	2784 (153)	2529 (217)	F(1, 98) = 26. 86, $p < .001$
3V-Female	F1	416 (29)	433 (22)	F(1, 88) = 3. 32, $p = .072$
	F2	2951 (129)	2928 (194)	F(1, 88) = . 314, $p = .577$
5V-Male	F1	337 (27)	408 (57)	F(1, 98) = 51. 81, $p < .001$
	F2	2490 (127)	2360 (99)	F(1, 98) = 19. 69, $p < .001$
4V-Male	F1	366 (41)	425 (75)	F(1, 93) = 23. 99, $p < .001$
	F2	2220 (104)	2076 (113)	F(1, 93) = 24. 12, $p < .001$
3V-Male	F1	359 (35)	412 (28)	F(1, 98) = 40. 43, $p < .001$
	F2	2171 (123)	2069 (140)	F(1, 98) = 9. 893, $p < .005$

The results indicate that most speakers' controversial [I/E] was significantly different from their non-controversial [i], in terms of both F1 and F2 values; the only exception was the 3-vowel female speaker, who made nearly no distinction between the two vowels. These results show that the front high vowels produced by the "3-vowel" speakers are lower than those of the "5-vowel" speakers, which suggests that the distance between the [i] and [I] is simply too short to form two distinctive levels of vowel height.

4.2 Back vowels: [u] vs. [U/O]

Likewise, there were significant effects for both factors Vowel and Gender on F1 and F2 values of back vowels (For [u]-[U/O] difference: F(1, 1216) = 176. 3, $p < .01$; for female/male difference: F(1, 1216) = 97.5, $p < .01$). Therefore, the non-controversial [u] differ from the controversial [U/O] with respect to F1 and F2 values. The results show that [U/O] is lower and more fronted than the [u]. As for the factor of Gender, the females' articulation of back vowels is lower and more fronted than the males'.

As far as the within-subject variation is concerned, Table 3 provides the formant values and the ANOVA results for the comparison of the two back vowels [u] and [U/O].

Table 3. Formant values (Mean/SD) of the back vowels

Mean (SD): Hz		[u]	[U/O]	ANOVA
5V-Female	F1	366 (44)	535 (69)	F(1, 118) = 469. 82, $p < .001$
	F2	992 (240)	1190 (154)	F(1, 118) = 24. 87, $p < .001$
4V-Female	F1	512 (76)	527 (45)	F(1, 118) = 1. 40, $p = .239$
	F2	956 (75)	1065 (217)	F(1, 118) = 5. 57, $p < .05$
3V-Female	F1	434 (28)	452 (58)	F(1, 118) = 3. 109, $p = .08$
	F2	940 (133)	1012 (144)	F(1, 118) = 6. 275, $p < .05$
5V-Male	F1	364 (24)	377 (41)	F(1, 118) = 3. 261, $p = .073$
	F2	912 (140)	1077 (444)	F(1, 118) = 7. 727, $p < .01$
4V-Male	F1	377 (44)	433 (40)	F(1, 113) = 41. 294, $p < .001$
	F2	944 (101)	993 (102)	F(1, 113) = 5. 446, $p < .05$
3V-Male	F1	368 (38)	409 (30)	F(1, 118) = 32. 365, $p < .001$
	F2	889 (113)	900 (127)	F(1, 118) = . 123, $p = .727$

As for back vowels, most speakers' controversial [U/O] and non-controversial [u] were significantly different in terms of F2 values, but not consistently different in terms of F1 values. The only exception was the 3-vowel male speaker, who did not exhibit significant differences in F2 values. The general pattern shown in Table 3 indicates that any speaker might exhibit significant differences between [u] and [U/O] in either F1 or F2, or both F1 and F2.

4.3 Stressed and unstressed conditions

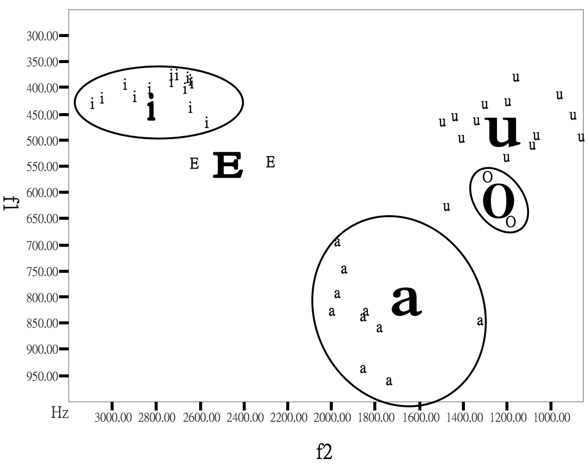
Figure 2 represents the speakers' vowel distribution in the unstressed condition. Although fewer tokens representing the controversial groups [I/E] and [U/O] were available, Figure 3 shows that some speakers separate the two pairs of vowels more clearly than others. The 5-vowel female, the 4-vowel female and the 4-vowel male made clearer distinctions than did the 5-vowel male, 3-vowel male and the 3-vowel female.[5] In addition, the male speakers have a more back and contracted vowel

[5] There is only one sample of the controversial vowel U/O on the 3-vowel female's and 3-vowel male's vowel distributions, because each of them has an outlier which falls outside the range. The 3-vowel female's outlier is 408 Hz F1 and 792 Hz F2, while the 3-vowel male's outlier is 500 Hz F1 and 826 Hz F2. Both are located far back in the vowel space.

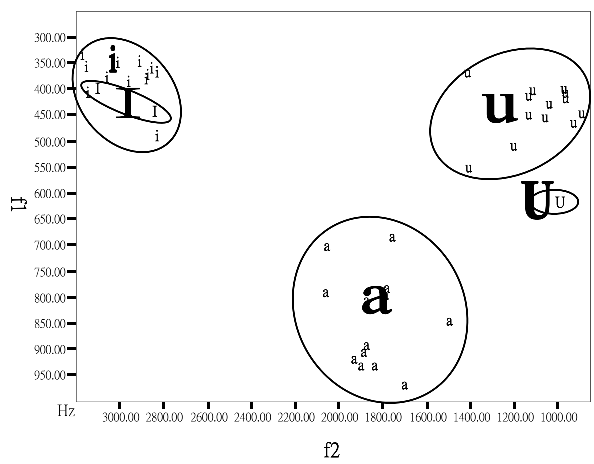
space than the female speakers do, which was also found in the stressed condition.[6]

The results of MANOVA showed that for the [i]-[I/E] pair, stress does not have a significant effect on the formant values produced, nor did stress interact with the factors Gender and Vowel Identity. In contrast, the effect of stress on formant production was found to be significant for the [u]-[U/O] pair ($F(1, 1216) = 69.5$, $p < .01$). We also found significant interaction of Stress with Gender and Vowel Identity for the [u]-[U/O] pair (Gender*Stress: $F(1, 1216) = 4.8$, $p < .01$; Vowel Identity*Stress: $F(1, 1216) = 39.8$, $p < .01$). In summary, the formant values of the [u]-[U/O] pair were found to be influenced by stress, while those of [i]-[I/E] pair were not.

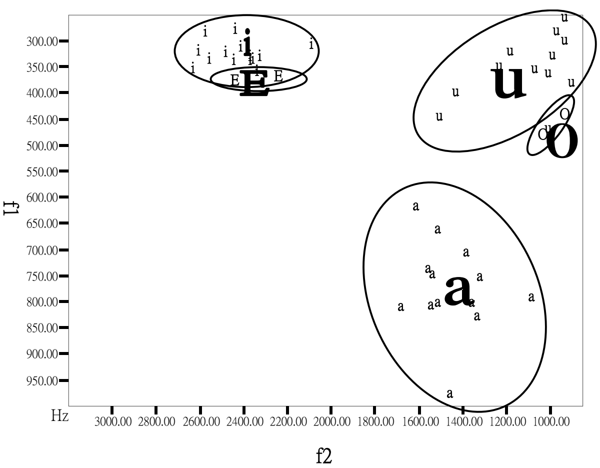
a. 5V-F's vowel distribution



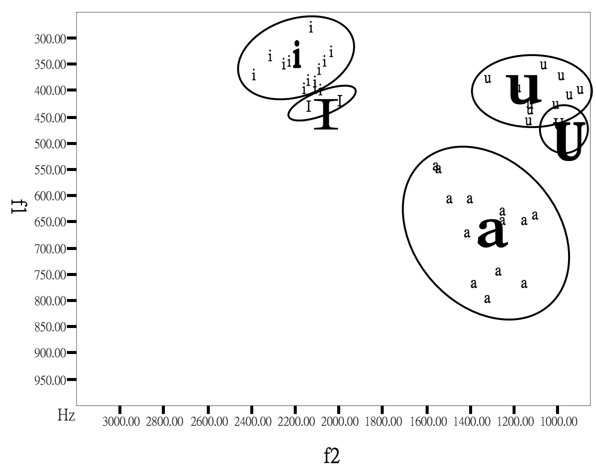
b. 3V-F's vowel distribution



c. 5V-M's vowel distribution

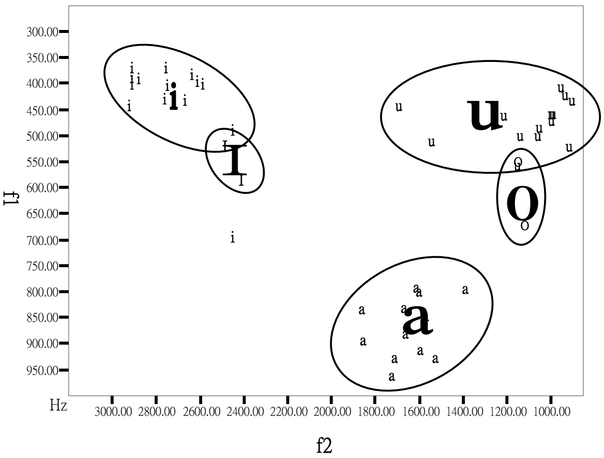


d. 3V-M's vowel distribution



[6] Due to the non-occurrence of the schwa /W/ in final unstressed syllables in Truku, these plots do not show schwa distribution.

e. 4V-F's vowel distribution



f. 4V-M's vowel distribution

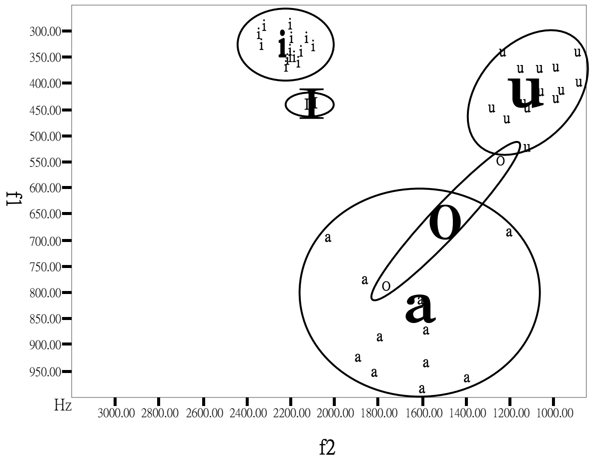
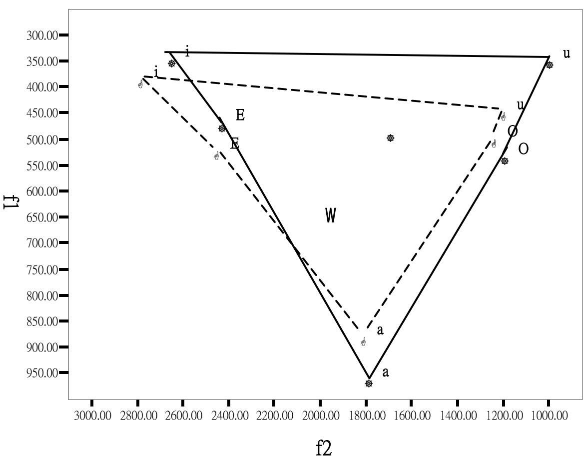
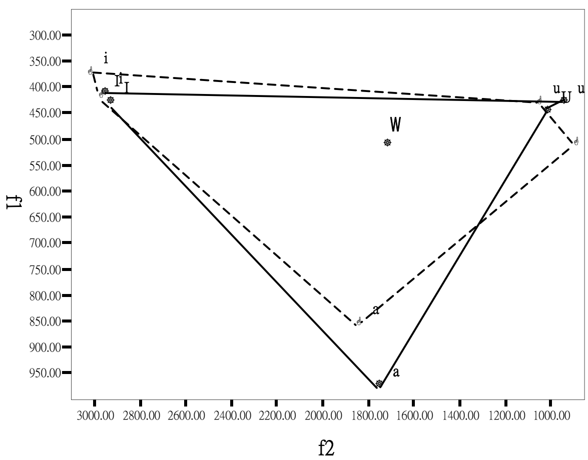


Figure 2. The six speakers' vowel distributions in the unstressed condition.

4.4 Vowel distance and vowel space

Figures 3.a-f display each speaker's vowel space in both stressed and unstressed conditions. From these displays, the following can be observed: (1) the vowel space seems slightly larger in the stressed than in the unstressed condition, (2) the distance between the vowels [i] and [I/E], or between [u] and [U/O] is greater in the unstressed than in the stressed condition.





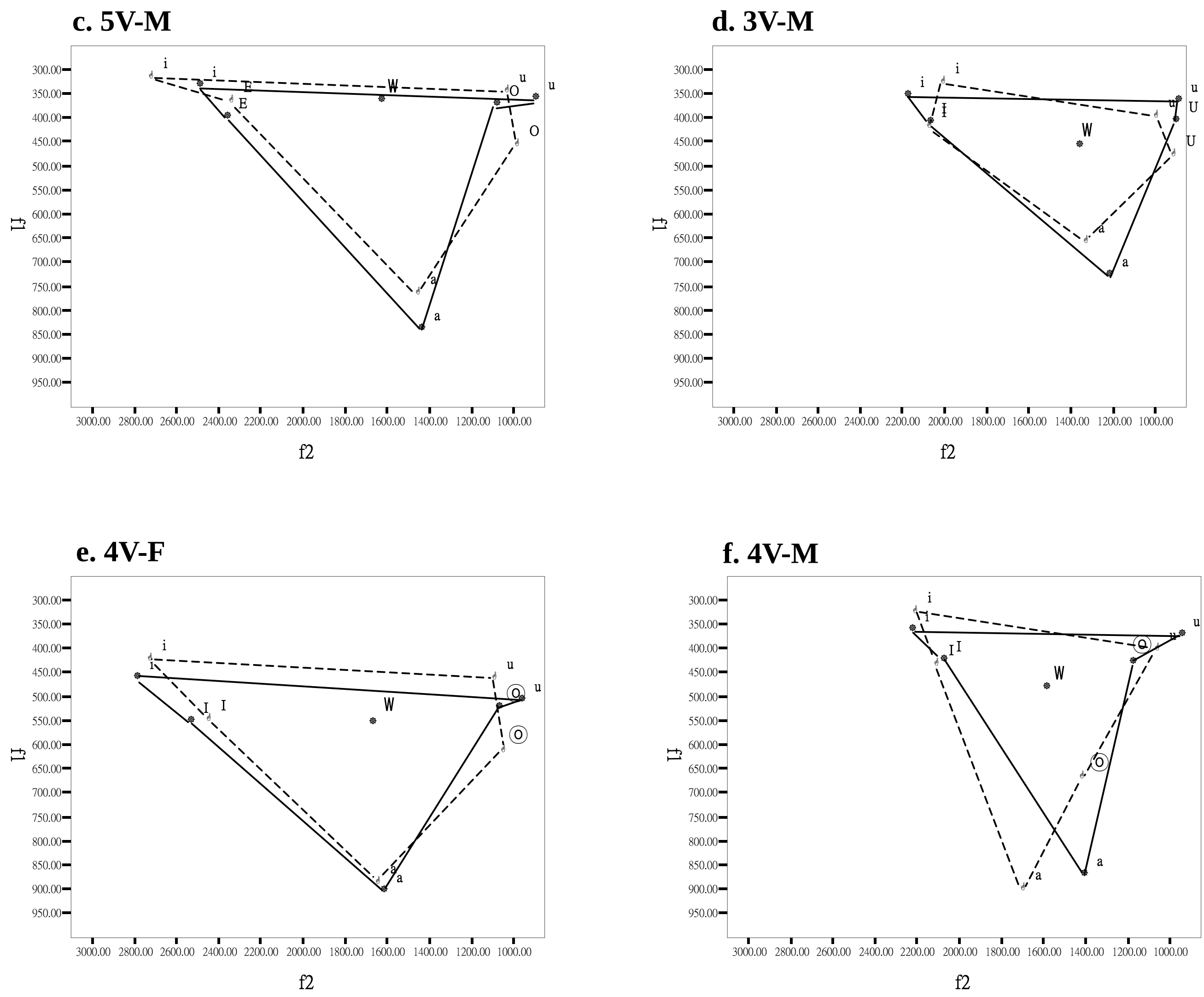


Figure 3. The vowel space of the six speakers. The filled cubes and lines represent the stressed condition, and the hollow cubes and dot lines represent the unstressed condition.

Table 4 provides further details about the influence of stress on vowel space. The area of the vowel space was calculated by a program[7] designed to divide the entire space into three triangles; the value of the whole space was derived by adding up the areas of those three triangles. Note that the areas of these spaces (in Hz^2) do not have any absolute significance, but can be used in a relative sense to compare one vowel space with another.

[7] We would like to thank Chung-ping Cheng, who wrote the vowel space measurement program.

Table 4. Stress-related variations in vowel space and the stressed/unstressed vowel space ratio. (Unit: Hz^2)

Speaker	Stressed	Unstressed	Shrinkage	Ratio (stressed: unstressed)
5V-Female	506303	354415	Shrink	**1: 0.70**
3V-Female	544587	451806	Shrink	**1: 0.83**
4V-Female	357832	411029	Expand	**1: 1.15**
5V-Male	350324	340722	Shrink	**1: 0.97**
3V-Male	244194	208259	Shrink	**1: 0.85**
4V-Male	262916	304063	Expand	**1: 1.16**

As shown in Table 4, the 5-vowel and the 3-vowel groups exhibit a shrinking vowel space in the unstressed condition. In contrast, the 4-vowel group exhibits an expanding vowel space in the unstressed condition. Moreover, the following gender differences in vowel space were observed: for female speakers, the 3-vowel speaker's vowel space was larger than the 5-vowel speaker's; whereas for male speakers, the 5-vowel speaker exhibited a larger vowel space than the 3-vowel speaker did.

Table 5 displays the vowel distances between [i] and [I/E], and between [u] and [U/O]. The distances were calculated using the Pythagorean Theorem, and vowel distance was derived by a radical expression.

Table 5. Stress-related variation in vowel distance and stressed/unstressed vowel distance ratio

Subject	[i]-[I/E]			[u]-[U/O]		
	Stressed	Unstressed		Stressed	unstressed	Ratio
5V-Female	252.23	358.93	**1: 1.42**	270.77	67.29	**1: 0.25**
3V-Female	29.21	62.68	**1: 2.15**	74.58	179.30	**1: 2.40**
4V-Female	270.82	306.24	**1: 1.13**	110	155.88	**1: 1.42**
5V-Male	146.07	381.79	**1: 2.61**	182.26	122.16	**1: 0.67**
3V-Male	115.63	111.26	**1: 0.96**	41.95	114.32	**1: 2.73**
4V-Male	159.61	150.44	**1: 0.94**	238.26	444.13	**1: 1.86**

Table 5 illustrates that the 5-vowel and the 3-vowel groups behave more regularly with respect to distance and ratio. First, the 5-vowel group usually exhibits a greater vowel distance than the 3-vowel group does between [i] and [I/E], and also between [u] and [U/O], in both stressed and unstressed conditions. The only exception to this observation is the vowel distance exhibited by the 5-vowel female speaker between [u] and [U/O] (67.29 Hz), which proved to be smaller than the 3-vowel female speaker's (179.30 Hz).

Next, the 3-vowel group usually has greater ratio of change in distance between vowels from stressed to unstressed conditions. One exception occurs in the case of the 3-vowel male speaker; his distance between [i] and [I/E] slightly decreased in the unstressed condition (1: 0.96). Note that unlike the other two groups, the 5-vowel group decreased the distance between [u] and [U/O] in the unstressed condition (1: 0.25 for female and 1: 0.67 for male). In summary, the 5-vowel group generally exhibits a greater distance between vowels than the 3-vowel group does, but a smaller ratio of distance change. The 4-vowel group exhibits fewer discernable patterns regarding vowel distance and ratio.

5. General discussion

This section will summarize the major observations of this study to address the research questions formulated in Section 2: (1) Can any version of Dispersion Theory account for variations in the reported number of Truku vowels, with respect to vowel space and vowel distance? (2) How do the factors of gender and lexical stress interact with vowel distribution and contrastiveness?

5.1 Dispersion Theory and vowel space

Adaptive Dispersion Theory claims that the overall size of a language's vowel space will increase in proportion to its vowel inventory size. This claim was confirmed by our male speakers. Table 4 shows that overall vowel space is largest for the 5-vowel male speaker, the second largest for the 4-vowel male speaker, and the smallest for the 3-vowel male speaker, both in stressed and unstressed conditions. However, our results showed that vowel space did not necessarily vary in proportion to inventory size, as demonstrated in the female speakers' data. When the number of vowels decreased from five to three, the 5-vowel female speaker exhibited a smaller vowel space than the 3-vowel female speaker did. This finding does not confirm Adaptive Dispersion Theory's prediction, according to which larger inventories should result in bigger vowel spaces. However, Flemming's version of Dispersion Theory can account for the bigger space observed in the 3-vowel female speaker's data. This version predicts that three functional goals can influence the ranking of phonological contrasts: (a) maximization of the distinctiveness of contrasts, (b) minimization of articulatory effort, and (c) maximization of the number of contrasts. These functional goals may be in conflict with each other (as described in

Section 2.2). Therefore, if a 3-vowel system prioritizes maximizing distinctiveness of contrasts and a 5-vowel system prioritizes the minimization of articulatory effort, the 3-vowel system will have a larger size than 5-vowel system does.

Although the 3-vowel female speaker produced lower high vowels than the 5-vowel female speaker did, her [i] was much more fronted and her [u] was much further back than that of the 5-vowel female speaker. The 3-vowel female speaker's larger vowel space can also be attributed in part to 'feministic' speech (Fant, 1975; Goldstein 1980). Goldstein (1980) also suggested that women tend to speak more clearly, and thus tend toward production of a wider vowel triangle. Diehl et al. (1996) points out that this preference may be culturally-specific; this study found at least one exception among Arabic speakers. In the current study, all female speakers exhibited an larger overall vowel space than male speakers did, as shown in Table 4. This finding corroborates the previous studies, in which female speakers' vowels were found to show greater between-category dispersion in the F1 $\times$ F2 plane than male speakers' vowels, which created a larger overall vowel space.

5.2 Dispersion Theory and vowel distance

As we had predicted, the vowel distance between controversial and non-controversial vowels was, for the most part, greater for the 5-vowel group than for the 3-vowel group. This result confirms Adaptive Dispersion Theory's prediction that vowel distance must be maximally dispersed, in order to form two distinctive categories. Furthermore, the 4-vowel group exhibited a pattern similar to that of the 5-vowel group with respect to the distribution of both front and back vowels. This contradicts our original hypothesis, in the sense that the distance between [i] and [I/E] should have been perceived to be smaller for the 4-vowel group, since for this group, front vowels all fall into the phonemic category /i/. Thus, neither Adaptive Dispersion Theory nor Flemming's Dispersion Theory can explain this result.

Back vowels, in contrast, confirm our predictions: the 4-vowel group exhibited greater distance between controversial [U/O] and non-controversial [u] than the 3-vowel group did, which can be accounted for by both versions of the Dispersion Theory. As seen in the following section, the 4-vowel group also exhibited unexpected results with respect to the change in vowel space between stressed and unstressed conditions. Future research will investigate the unexpected phenomena shown in the 4-vowel group.

5. 3 The effect of stress on vowel contrasts

Whether a particular vowel occurred in a stressed or an unstressed position proved to have an effect on both the size of the vowel space and the distance between vowels in a particular inventory. The 5-vowel and the 3-vowel speakers' vowel spaces shrank when moving from the stressed to the unstressed condition, whereas their vowel distances tended to expand. Shrinkage of the vowel space has two possible explanations: the first rests on the phonotactic distribution of the schwa in Truku, i.e. that the schwa never occurs in a final unstressed syllable. This obviates the need to form a contrast between full vowels and [ə], which would result in a decrease in the overall vowel space for the purpose of minimizing articulatory effort. The second possibility is that the low vowel [a] has been raised in unstressed conditions. Flemming (2004) suggested that the reduction in vocalic duration occurring in unstressed syllables gives rise to articulatory difficulties, especially for low vowels, which would motivate vowel raising. This hypothesis is confirmed by our research (see Figures 3.a-3.d).

Measurement of the distance between vowels in unstressed conditions, in contrast, produced equivocal results. Vowel distance was not found to be reduced in unstressed conditions. Instead, most of the speakers showed enlarged distances between controversial and non-controversial vowels occurring in unstressed syllables. Moreover, the ratios of distance change were asymmetrical between front and back vowels. For example, in the 5-vowel group, vowel distance increased between [i] and [I/E] but decreased between [u] and [U/O]. Similarly, the 3-vowel and the 4-vowel male speakers slightly shortened the distance between [i] and [I/E], but enlarged the [u]-[U/O] distance.

Moreover, the vowel space of the 4-vowel group expanded in unstressed conditions, rather than shrinking as it had in the 5-vowel and the 3-vowel group conditions. In addition, the low vowel [a] did not rise, as it had in the other groups. This issue will be addressed in future research.

6. Conclusion

This study uses predictions formulated by Dispersion Theory to investigate the dispersion of vowel space and vowel distance in Truku, as well the ways in which they interact with gender and lexical stress. Subject-based comparisons across vowel inventory variations revealed that the 5-vowel and the 3-vowel groups behaved more regularly, while the 4-vowel group exhibited fewer discernable patterns. The differences observed between the 5-vowel and the 3-vowel groups in terms of overall vowel space and vowel distance can be successfully accounted for by the combination of two versions of Dispersion Theory. Gender differences shown in vowel space size corroborated the claims of previous research. Our hypothesis with respect to stress was confirmed: in stressed conditions, vowel distribution was linked to vowel inventory size. In addition, stress was found to influence vowel distribution with respect to the overall space and distance between vowels.

Future research is needed to further investigate the unexpected behavior shown by the 4-vowel group. The results of this study suggest that Truku exhibits dialectal differences in terms of vowel inventory, although there are theories that attribute these differences to allophonic or free variation.

Finally, this study may also shed light on the discussion of vowel inventories in other Formosan languages of Taiwan. As the sense of identity grows stronger among indigenous peoples of Taiwan, there has been an increased interest in establishing writing systems for indigenous languages. However, judgments about the number of phonemes in a language's inventory often differ in the accounts of linguists and native speakers. Further collaborative research between linguists and native informants is needed to investigate the vowel systems of other Formosan aboriginal languages, in order to provide support for our Truku data.

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[Received 18 March 2005; revised 12 May 2005; accepted 26 May 2005]

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太魯閣語之母音分散

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本研究探討太魯閣語中母音空間與距離的分散現象，以及性別和重音對此母音分散的影響。本研究依照發音人對太魯閣語母音數目的認知，將他們分爲五母音組、四母音組及三母音組。實驗的語料包括七十七個雙音節單字，由發音人唸過之後再測量其母音共振峰的值。結果顯示，相較於四母音組較不規則的母音分散型態，五母音和三母音組呈現較爲可辨別的分散型態。本研究引用兩種分散理論來解釋五母音與三母音組之間的母音分散空間和距離的差異。性別因素對於母音空間的影響也與過去的研究結果相符。此外，本研究也發現重音對母音分散的影響是同時作用於「母音空間」及「母音間距離」這兩個層面。

關鍵詞：太魯閣語、母音分散、母音空間、母音距離、性別因素、重音因素