

English /l/s as Produced by Native English and Mandarin Chinese Speakers

by

Nan Xing
B.A., Tianjin University, 2012

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF ARTS

in the Department of Linguistics

© Nan Xing, 2014
University of Victoria

All rights reserved. This thesis may not be reproduced in whole or in part, by photocopy or other means, without the permission of the author.

Supervisory Committee

English /l/s as Produced by Native English and Mandarin Chinese Speakers

by

Nan Xing
B.A., Tianjin University, 2012

Supervisory Committee

Dr. Hua Lin, (Department of Linguistics)
Supervisor

Dr. John H. Esling, (Department of Linguistics)
Departmental Member

Abstract

Supervisory Committee

Dr. Hua Lin, (Department of Linguistics)
Supervisor

Dr. John H. Esling, (Department of Linguistics)
Departmental Member

The present study examines the acoustic and articulatory features of English onset and coda /l/s as produced by native English and Mandarin Chinese speakers in the vowel contexts of /i/, /ɪ/, /e/, /ɛ/, /u/, /ʊ/, /o/, /ɔ/, /ɑ/, /ʌ/, /ɚ/, and /æ/, and via the elicitation tasks of word list and mini dialogue. Four Mandarin Chinese speakers who had lived in Canada for at least one year by the time of the experiment and four Canadian English speakers who were born and raised on west coast of Canada participated in the research. Both groups of speakers were the graduate students studying at the University of Victoria.

The experiment took place at the Phonetics Laboratory in the Department of Linguistics at the University of Victoria. An ultrasound machine together with a synchronized microphone was used to record the speech data for analysis. The results showed that for onset /l/, the tongue position of the Mandarin Chinese speakers was more front than that of the English speakers. For coda /l/s, Mandarin Chinese speakers had lower and more retracted tongue position than their English counterparts. ANOVA tests showed that vowel contexts and task formality had limited impact on the acoustic qualities of the onset and coda /l/s produced by both groups of speakers. The results and conclusions from the present study will contribute to a better understanding of the

articulatory features of the English /l/s. Mandarin Chinese learners may also benefit from this study in that they could potentially improve their pronunciations and reduce accent.

Table of Contents

Supervisory Committee	ii
Abstract	iii
Table of Contents	v
List of Tables	vii
List of Figures	viii
Acknowledgments	x
Chapter 1 Introduction	1
1.1 Research Questions	3
1.2 Organization	4
Chapter 2 Literature Review	5
2.1 Classification of Clear and Dark /l/s	5
2.2 Articulatory features of Clear and Dark /l/s	6
2.3 Acoustic Features of Clear and Dark /l/s	11
2.4 Gestural Model on Clear and Dark /l/ Production	13
2.5 Using Ultrasound in Articulatory Studies	14
Chapter 3 Method	16
3.1 Participants	16
3.2 Stimuli	16
3.3 Data Collection	17
3.4 Data Analyses	19
3.4.1 Acoustic measurements	19
3.4.2 Ultrasound measurements	21
3.5 Statistical Data Analyses	25
Chapter 4 Results	27
4.1 Research Question 1: /l/ production by Canadian English speakers	27
4.2 Research Question 2: /l/ production by Mandarin Chinese speakers	37
4.3 Research Question 3: Vowel Contexts	46
4.4 Research Question 4: Elicitation tasks	60
4.5 Research Question 5: Comparison between English and Chinese speakers	65
Chapter 5 Discussion and Conclusion	76
5.1 Key Findings	76
5.1.1 Acoustic and articulatory features of onset and coda /l/s as produced by Canadian English speakers	76
5.1.2 Acoustic and articulatory features of onset and coda /l/s as produced by Mandarin Chinese speakers	78
5.1.3 The influence of vowel context on onset and coda /l/ production	80
5.1.4 The influence of task formality on onset and coda /l/ production	80
5.1.5 The similarities and differences between Canadian English speakers and Mandarin Chinese speakers	81
5.2 Summary and Conclusion	82
Bibliography	87
Appendix 1 Speech Stimuli	95

Appendix 2 Language Background Survey 97

List of Tables

Table 3.1 Stimuli for single /l/ in coda and onset positions.....	17
Table 3.2 Coda and onset /l/ tokens and EdgeTrak name correspondence.....	23
Table 4.1 Descriptive statistics for formant values of /l/s produced by English speakers in word list task.....	28
Table 4.2 Descriptive statistics for speech data produced by English speakers in mini dialogue task.....	33
Table 4.3 Descriptive statistics for speech data produced by Mandarin Chinese speakers in word list task.....	38
Table 4.4 Descriptive statistics for speech data produced by Mandarin Chinese speakers in mini dialogue task.....	42
Table 4.5 Four-way ANOVA test results for vowel context analysis (F1).....	47
Table 4.6 Tukey test results for vowel context analysis (F1).....	48
Table 4.7 vowel – number correspondence.....	48
Table 4.8 Four-way ANOVA test results for vowel context analysis (F2).....	53
Table 4.9. Tukey test results for vowel contexts (F2).....	53
Table 4.10 Four-way ANOVA test results for vowel context analysis (F3).....	58
Table 4.11 Four-way ANOVA test results for elicitation tasks analysis (F1).....	61
Table 4.12 Four-way ANOVA test results for elicitation tasks analysis (F2).....	62
Table 4.13 Four-way ANOVA test results for elicitation tasks analysis (F3).....	64
Table 4.14 Descriptive statistics for group comparison (F1).....	65
Table 4.15 Four-way ANOVA test results for group comparisons (F1).....	66
Table 4.16 Descriptive statistics for group comparison (F2).....	68
Table 4.17 Four-way ANOVA test results for group comparisons (F2).....	69
Table 4.18 Descriptive statistics for group comparison (F3).....	71
Table 4.19 Four-way ANOVA test results for group comparisons (F3).....	71
Table 4.20 Group comparison results for onset /l/ in word list task.....	73
Table 4.21 Group comparison results for coda /l/ in word list task.....	74
Table 4.22 Group comparison results for onset /l/ in mini dialogue task.....	74
Table 4.23 Group comparison results for coda /l/ in mini dialogue task.....	75

List of Figures

Figure 2.1. Midsagittal tracings of the vocal tracts for different subjects during /l/ production (four subjects AK, MI, PK, and SC) (Narayanan et al., 1997).....	8
Figure 2.2 Area functions for different subjects during /l/ production (four subjects AK, MI, PK, and SC) (Narayanan et al., 1997).....	9
Figure 2.3 Spectrograms of word “feel” and word “light”. (a) “fell” (dark /l/, syllable final), and (b) “light” (light /l/, syllable initial) (Zhou, 2009).	12
Figure 3.1 Labelling of the word “mail”	20
Figure 3.2 Labelling of the word “lay”	21
Figure 3.3 Tongue curve showing red dots from EdgTrak.	24
Figure 4.1 Average tongue contours of English Participant 1 in word list task	30
Figure 4.2 Average tongue contours of English Participant 2 in word list task	31
Figure 4.3 Average tongue contours of English Participant 3 in word list task	32
Figure 4.4 Average tongue contours of English Participant 4 in word list task	33
Figure 4.5 Average tongue contours of English Participant 1 in mini dialogue task	34
Figure 4.6 Average tongue contours of English Participant 2 in mini dialogue task	35
Figure 4. 7 Average tongue contours of English Participant 3 in mini dialogue task	36
Figure 4.9 Average tongue contours of Chinese Participant 1 in word list task.....	39
Figure 4.10 Average tongue contours of Chinese Participant 2 in word list task.....	40
Figure 4.11 Average tongue contours of Chinese Participant 3 in word list task.....	41
Figure 4.12 Average tongue contours of Chinese Participant 4 in word list task.....	41
Figure 4.13 Average tongue contours of Chinese Participant 1 in mini dialogue task.....	43
Figure 4.14 Average tongue contours of Chinese Participant 2 in mini dialogue task.....	44
Figure 4.15 Average tongue contours of Chinese Participant 3 in mini dialogue task.....	45
Figure 4.16 Average tongue contours of Chinese Participant 4 in mini dialogue task.....	45
Figure 4.17 Normal distribution test (QQ Plot) for F1	46
Figure 4.18 vowel contexts and /l/ variations (F1)	49
Figure 4.19 Vowel contexts and groups of speakers (mean F1).....	50
Figure 4.20 Vowel contexts and task formalities (mean F1)	51
Figure 4.21 Normal distribution test (QQ Plot) for F2	52
Figure 4.22 Vowel contexts and /l/ variations (F2)	54
Figure 4.23 Vowel contexts and groups of speakers (mean F2).....	55
Figure 4.24 Vowel contexts and task formalities (mean F2)	56
Figure 4.25 Normal distribution test (QQ Plot) for F3	57
Figure 4.26 Vowel contexts and /l/ variations (mean F3).....	58
Figure 4.27 Vowel contexts and groups of speakers (mean F3).....	59
Figure 4.28 Vowel contexts and task formalities (mean F3)	60
Figure 4.29 Mean F1 comparisons between the two elicitation tasks (mean F1).....	62
Figure 4.30 Mean F2 comparisons between the two elicitation tasks (mean F2).....	63
Figure 4.31 Mean F3 comparisons between the two elicitation tasks (mean F3).....	64
Figure 4.32 Groups of speakers and /l/ variations (mean F1).....	67
Figure 4.33 Groups of speakers and task formalities (mean F1)	67
Figure 4.34 Groups of speakers and /l/ variations (mean F2).....	69
Figure 4.35 Groups of speakers and task formalities (mean F2)	70

Figure 4.36 Groups of speakers and /l/ variations (mean F3)..... 72
Figure 4.37 Groups of speakers and task formalities (mean F3)..... 73

Acknowledgments

People say that life is a journey. On the journey of my graduate study, I was very fortunate to meet and know so many wonderful people who helped me learn and grow. First and foremost, I am deeply indebted to my supervisor, Dr. Hua Lin, whose insightful academic guidance as well as kind and inspiring words can never be fully reciprocated. I thank her for showing me the tools of doing research, for encouraging me to explore areas I was not so familiar with, for being there when I needed support, and most of all, for believing and trusting me when I was at my low points. I will always remember the moments when Dr. Lin sat down with me going over her notes with me, when she read my thesis late at night trying to give me revise advices in time, when she left heart-warming comments on my Facebook page encouraging me to do better, and when she walked with me talking about random things in life. I am so fortunate that our paths crossed and to study and work with her.

I also appreciate the support of Dr. John Esling on understanding the physiological mechanism of human speech production. I thank him for being my course instructor for two terms and for being on my thesis committee giving me valuable suggestions on how to improve my paper. I am grateful to Dr. Tsung-Cheng Lin for his quick and insightful feedback that helped me see things from a different angle.

I benefited from lessons and meetings with UVic faculty and staff members whose help has been invaluable. I would like to thank Dr. Sonya Bird, Dr. Dave McKercher, Dr. Ewa Czaykowska-Higgins, Dr. Li-Shih Huang, and Dr. Leslie Saxon for their excellent classes

and for their support throughout the program. I also appreciate the technical and administrative support from Chris Coey, Jenny Jessa, and Maureen Kirby.

I wish to extend my sincere thankfulness to my friends at UVic for their support and advices. I am thankful to Adar Anisman, Mengyue Cai, Hailey Hyekyeong Ceong, Marianne Huijismans, Yuriko Katsumata, Jongmin Kim, Natallia Litvin, Akitsugu Nogita, Janelle Serediak, Ross Zariski, and Jessie Zhou.

I also owe an immense debt of gratitude to my family. I would like to say an earnest thank you to my parents for their unconditional support and companionship while I am finishing my study in Canada. Their understanding and belief in me has always been a source of motivation for me.

Finally, I would like to acknowledge the financial support that has helped me to complete my MA studies. I thank the Department of Linguistics for employing me as a Teaching Assistant, and the University of Victoria for an M.A. Scholarship, and Henry and Michiko Warkentyne Graduate Scholarship.

Chapter 1

Introduction

Since the mid-1970s, a broad range of studies has been carried out on the articulatory and acoustic properties of /l/ across languages (e.g., Browman & Goldstein, 1995; Ding & Jokisch, 2010; Narayanan, 1997; Raphael, 1972; Recasens, 2012; Simonet, 2010; Sproat et al., 1993; Turton, 2011; Wrench, 2003). Laterals in many languages display a considerable degree of allophonic and acoustic variation, while as Ladefoged (1996) pointed out, the most common laterals are voiced lateral approximants. Two varieties of lateral approximants have been identified: clear and dark /l/s. The word “dark” is attributed to the lower pitch found in velar and velarized consonants (Ball et al., 2000). In the *Encyclopedia of Language and Linguistics* (2nd Edition), clear /l/ is defined as, “a lateral sound that is made without velarization”, whereas dark /l/ is defined as, “a lateral sound produced with the back of the tongue raised, velarizing the sound”.

In the case of /l/ velarization, Ladefoged and Johnson (2011) pointed out that in both British and American English, the center of the tongue is pulled down and the back is arched up as in a back vowel. The contact on the alveolar ridge forms the primary articulation and the arching upward of the back of the tongue forms a secondary articulation, which, according to Ladefoged and Johnson, is called velarization (more explanation about “velarization” is given in Chapter 2.2 – Articulatory Features of Clear and Dark /l/s). They further presented that in American English, all variations of /l/ are comparatively velarized, except those that are in syllable initial position.

Not all scholars share the same position with Ladefoged and Johnson (2011) concerning velarization, the secondary articulation feature of dark /l/. Sproat and

Fujimura (1993), for instance, did not find the tongue dorsum rising towards the velum in their study as was suggested by previous studies. They concluded accordingly that tongue retraction and lowering of the tongue dorsum were the second articulatory features of dark /l/s.

What is the distinctive articulatory feature of dark /l/ compared with clear /l/? Is it velarization as suggested in Clark & Yallop, 1995; Ladefoged and Johnson, 2011 or pharyngealization as suggested in Narayanan & Alwan, 1997; Recasens and Espinosa, 2005? How do we explain the contradictory data observed in dark /l/ studies with regard to place of articulation and tongue configurations? Do the articulatory and acoustic features of clear and dark /l/s differ in different vowel contexts? Are there any differences between the /l/ production of native Canadian English speakers and Mandarin ESL speakers? If there are differences, do the degree of deviations vary according to vowel contexts? How does formality (word-list reading versus mini-dialogue/spontaneous speech) impact on the quality of Mandarin ESL (English as Second Language) speakers' productions? These are the questions that will be addressed in this thesis.

To answer the first question, ultrasound experiment were conducted to compare native speakers' clear and dark /l/s produced in word-list reading and mini-dialogue tasks. To further explore the articulatory and acoustic features of the /l/ variations, eleven vowel contexts are created to elicit speech data. I used four-way ANOVA and repeated one-way ANOVAs to compare formant values of clear and dark /l/ productions by native and Mandarin ESL speakers.

Weinberger (1987) proposed that formality and ESL speakers' proficiency levels are the reasons for the different qualities in their speech production. Word-list reading is

considered to be the most formal way of testing speaker's production, while spontaneous speech in a relaxed environment is considered to be the least formal way of collecting speech data. According to Weinberger's (1987) observation, Mandarin ESL speakers tend to use an epenthesis strategy in word-reading tasks and deletion in spontaneous speech. In the present study, word-list reading and mini-dialogue tasks will be used to elicit speech data. Although mini-dialogue is more controlled than spontaneous speech, it is more efficient in collecting the target words.

Finally, a comparison of the articulatory and acoustic features of the clear and dark /l/s in eleven vowel contexts (/i/, /ɪ/, /e/, /ɛ/, /u/, /ʊ/, /o/, /ɔ/, /ɑ/, /ɒ/, /ɔ̃/, and /æ/) and two elicitation tasks (word-list reading and mini-dialogue) will be done to find the similarities and differences between the /l/ productions of native Canadian English speakers and Mandarin ESL speakers.

1.1 Research Questions

The present study will recruit four native English speakers and 4 Mandarin Chinese ESL speakers who are at high-intermediate and advanced proficiency levels. The research purposes are to identify and analyze the articulatory and acoustic features of clear and dark /l/s in English and to find the similarities and differences between the productions of native English speakers and Mandarin Chinese ESL speakers.

Specifically, this study explores the answers to the following five questions:

1. What are the acoustic and articulatory features of clear and dark /l/s produced by native English speakers?
2. What are the acoustic and articulatory features of clear and dark /l/s produced by Mandarin Chinese ESL speakers?

3. Do vowel contexts have an impact on the acoustic features in the native and non-native production of clear and dark /l/s?

4. Does the formality of elicitation tasks (i.e., word-reading versus mini-dialogue) have an impact on the acoustic features in the production of native and non-native /l/ variations?

5. What are the similarities and differences between the /l/ productions of native English and Mandarin ESL speakers under different circumstances of vowel contexts and formality of task?

1.2 Organization

This thesis includes five chapters. This chapter is an Introduction Chapter. Chapter Two reviews relevant literature concerning the definitions and classifications of clear and dark /l/s, the articulatory and acoustic features of /l/ variations, the Gestural model in explaining the differences between clear and dark /l/s, and the usage of ultrasound in exploring the articulation process of /l/s. Chapter Three introduces the methodology used in this research including the information on participants, speech stimuli, data collection methods, and the data analyses. Chapter Four presents the production results according to the five proposed research questions as well as the results of quantitative analyses. Chapter Five is the discussion and conclusions chapter. It discusses the main findings of this study and the pedagogical implications for teaching Mandarin ESL learners the English dark /l/s. It also addresses the limitations of the present study and suggests additional studies to examine the issues concerning the clear and dark /l/s produced by Mandarin ESL speakers.

Chapter 2

Literature Review

In order to identify and analyze the articulatory and acoustic features of /l/ variations in English and to find the similarities and differences between the production of native English speakers and Mandarin Chinese ESL learners, the researcher have reviewed a range of literature on clear and dark /l/ studies. This literature review includes five sections: the definition and classification of clear and dark /l/s, the articulatory features of clear and dark /l/s, the acoustic features of clear and dark /l/s, the gestural model on clear and dark /l/ production, and ultrasound usage in articulation studies.

2.1 Classification of Clear and Dark /l/s

The two categories of lateral approximants, namely, clear and dark /l/s, are not agreed upon with all researchers. Articulatory and acoustic data reveal that the clear distinction between clear and dark /l/ is hard to pinpoint (Recasens 2004, 2012). Recasens (2012) proposed that instead of considering a binary distinction between clear and dark /l/s, researchers could classify /l/s into three categories: a strongly dark, a strongly clear, and a moderately clear/dark variety of /l/.

From an intra-language point of view, the two allophones of /l/ seem insufficient to represent all phonetic variations as well. In English, pre-vocalic /l/s are considered as clear /l/s and post-vocalic /l/s are regarded as dark /l/s, yet, the intervocalic /l/s (e.g., /l/ in *feel it*), according to Sproat and Fujimura (1993), demonstrate an intermediate quality between the light and dark variations. Magnuson (2008) also pointed out that in Kansai Japanese the acoustic qualities of /l/ are highly context dependent. The diversity of /l/

variations calls for a more specific and precise way of demonstrating the degree of darkness/lightness in studies.

Since the present study tries to investigate Mandarin Chinese speakers' production of English clear and dark /l/s and to compare the differences between Mandarin speakers' and the native English speakers' /l/ production, the binary classification will be used for ease of comparison, yet, the formant frequency values for /l/s will also be presented to indicate the degree of darkness/lightness of participants' production.

2.2 Articulatory features of Clear and Dark /l/s

Although a broad range of literatures share the common ground that velarization of the tongue dorsum towards the back of the vocal tract and reduction of tongue-tip movements in the alveolar region are the distinctive features of dark /l/s compared with clear /l/s (e.g., Browman & Goldstein, 1995; Clark & Yallop, 1995; Narayanan & Alwan, 1997; Recasens, 2004; Wrench, 2003; Yang, 2008), there are scholars who hold different opinions on the concept of velarization and on the nature of tongue movements in the alveolar region.

The definition of velarization given by Clark and Yallop (1995) is that, “velarization involves moving the tongue body and root towards the back of vocal tract, forming a tongue shape that is similar to the vowels [u] and [ɔ] (p.65)”, yet, it does not describe precisely what do the tongue configurations of the vowels look like. Another definition given by Recasens (2004) says that, velarization conveys “a decrease in degree of linguopalatal contact both at palatal zone and at the post alveolar zone (p.962)”. In this definition, Recasens (2004) relates velarization with the tongue movements in the front-

middle or middle part of the vocal tract, instead of the back of the vocal tract (i.e., velar and pharyngeal regions), as is proposed by Narayanan and Alwan (1997).

Sproat and Fujimura (1993) even pointed out that velarization is not the articulatory feature of dark /l/s at all. They argued that a velarized sound ought to show significant rising of the tongue dorsum towards the velum, yet in their studies the dorsum showed no signs of raising towards the velum. They concluded that greater degree of tongue retraction and lowering of the tongue dorsum were the articulatory features of dark /l/s.

A possible explanation for the divergent understanding concerning the place of articulation of dark /l/s may be that instead of raising the back part of tongue dorsum and the tongue root to achieve the velarization, speakers may actually lower the velar part by constricting the muscles in the velar-pharyngeal regions to produce dark /l/s. Recasens and Espinosa (2005) later pointed out that the main differences between clear and dark /l/s may be the presence or absence of a post dorsal constriction at the velar or upper pharyngeal region, which indicates the alternative hypothesis that lowering velar or upper pharyngeal regions instead of raising the tongue root is the reason for the velarization of dark /l/s.

High degree of interpersonal variations in the production of clear and dark /l/s may be an alternative way of understanding the researchers' divergent position on velarization.

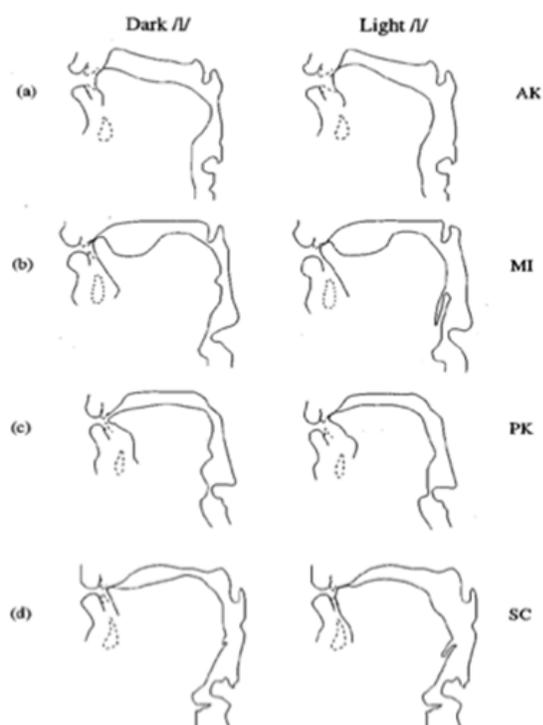


Figure 2.1. Midsagittal tracings of the vocal tracts for different subjects during /l/ production (four subjects AK, MI, PK, and SC) (Narayanan et al., 1997).

As is shown in Figure 2.1, the four subjects' production of clear and dark /l/s vary considerably with regard to tongue configurations. For speaker AK, constriction near the pharyngeal region is obvious; for speaker MI and PK, tongue raising towards velar or uvular regions is present; for speaker SC, the narrow path is formed near the palatal and the velar areas. Those interpersonal differences may contribute to the difficulty of reaching a consensus on the process of velarization.

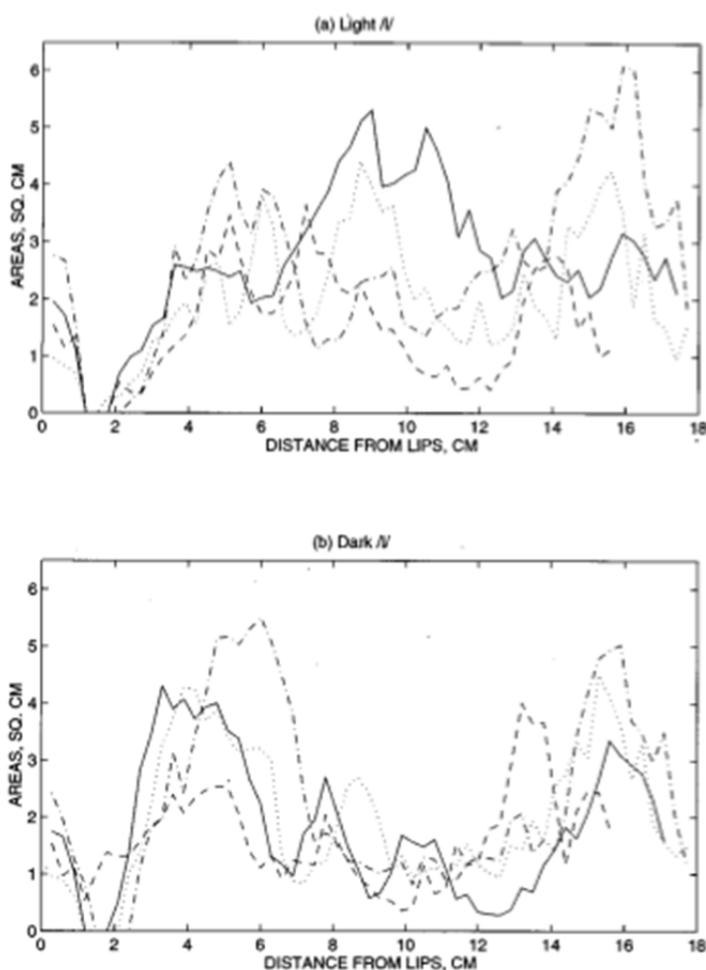


Figure 2.2 Area functions for different subjects during /l/ production (four subjects AK, MI, PK, and SC) (Narayanan et al., 1997).

Despite the high degree of interpersonal variances, we can still catch the general tendency through Figure 2.2. The area functions shown above are measured in cm^2 . The solid line represents the production of AK; the dashed line is used to represent PK; the dot-dashed line represents speaker MI; and the dotted line is used depict SC's production. Narayanan et al. (1997) present that, "the region about 1.5-2.5 cm from the lips is the alveolar region, 2.5-6 cm is the palatal region, 6-8.5 cm is the velar region, 8.5-13 cm is

the uvular and upper-pharyngeal region, and 13-15 cm is the lower-pharyngeal region (p.1067). From Figure 2.2 we can see that between 6 to 13 cm from the lips, the areas of function differ significantly between clear and dark /l/s, which indicates that tongue configurations of the two /l/ variations near the velar, uvular, and upper-pharyngeal regions are significantly different. This conclusion may support the idea that the secondary place of articulation difference between clear and dark /l/ lies between the velar to upper-pharyngeal region (velarization and pharyngealization), instead of just velar region (velarization).

Regarding the tongue configurations at the front of the vocal tract, a number of scholars (e.g., Ladefoged & Maddieson, 1996; Recasens, 2004; Wrench, 2003; Yang, 2008) agree that dark /l/ is apical articulation with little or no contact at the alveolar ridge, whereas clear /l/ is laminal articulation with greater contact at the alveolar ridge. Browman and Goldstein (1995) also found the same articulatory features for the differences between clear and dark /l/s in the front part of vocal tract. They further presented a tongue-tip-movement reduction model, which said that dark /l/s were not only apical articulations, but also were produced with less tongue-tip movements compared with clear /l/s.

The arguments concerning the articulatory features of clear and dark /l/s converged on the tongue movements or the process of velarization or pharyngealization at the back part of the vocal tract. As is concluded by Narayanan and Alwan (1997), “the overall 3-D tongue body shape – alveolar contact, lateral compression, and convex tongue body for [l] and [ɫ] were similar although the tongue body position in the velar and pharyngeal regions were different (p.1072)”.

In addition to the divergent articulatory features of clear and dark /l/s mentioned above, namely, velarization versus non-velarization and apical articulation versus laminal articulation, there is one more significant difference between clear and dark /l/s. For dark /l/s, the presence of tongue dorsal retraction and lowering comes earlier than the apical advancement; whereas for clear /l/s, the tongue dorsal movements are relatively later than the apical configuration (Sproat and Fujimura, 1993). Proctor (2009) found the same sequential differences between clear and dark /l/s from his researching using ultrasound.

In the present study, difference between tongue configurations and gestural sequence in the production of English clear and dark /l/s by native speakers and Mandarin ESL (English as a Second Language) speakers will be examined by using both acoustic analysis and ultrasound imaging.

2.3 Acoustic Features of Clear and Dark /l/s

Acoustically, dark /l/ is characterized by a relative lower F_2 and higher F_1 compared to the F_2 and F_1 values of clear /l/ (e.g., Narayanan & Alwan, 1997; Recasens & Espinosa, 2005; Sproat & Fujimura, 1993). The MRI-based articulatory and acoustic study carried out by Zhou (2009) that both clear and dark /l/s have relatively weak energy in the F_3 - F_5 region and that dark /l/s and light /l/s differ in the number and locations of zeros in the spectrum due to different contact places in the vocal tract.

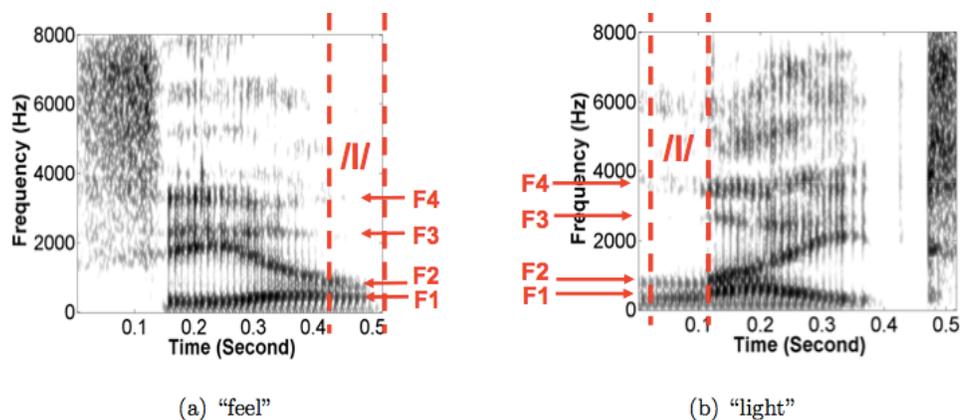


Figure 2.3 Spectrograms of word “feel” and word “light”. (a) “fell” (dark /l/, syllable final), and (b) “light” (light /l/, syllable initial) (Zhou, 2009).

According to Espy-Wilson (1992), another acoustic difference between clear and dark /l/s is the transition pattern between /l/ and the following vowel. In the case of clear /l/, there is a sudden shift up of F_1 from the /l/ to the following vowel, whereas for dark /l/s there is no abrupt change in the transition section. This may be explained by the basic acoustic features of clear and dark /l/. The study also reported that the average formant frequencies of prevocalic /l/ are: F1 399 Hz, F2 1074 Hz, F3 2533 Hz, F4 3767 Hz. The average formant frequencies of intervocalic /l/ are: F1 445 Hz, F2 1060 Hz, F3 2640 Hz, F4 3762 Hz. Finally the average formant frequencies of postvocalic /l/ are: F1 465 Hz, F2 898 Hz, F3 2630 Hz, F4 3650 Hz.

Since /l/ sounds can vary considerably among different speakers and contexts (e.g., Ladefoged, 1996; Narayanan & Alwan, 1997; Recasens, 2012; Zhou, 2009), it is very difficult to characterize /l/ sounds using a set of strict articulatory and acoustic norms. For this study, the average formant frequencies of clear and dark /l/s produced by both native

English speakers and L2 Mandarin Chinese speakers will be presented and compared with previous studies.

2.4 Gestural Model on Clear and Dark /l/ Production

A number of studies (e.g., Clark & Yallop, 1995; Giles & Moll, 1975; Ladefoged, 1996; Sproat & Fujimura, 1993) have shown that the articulatory feature of dark /l/ resembled that of back vowels instead of a consonant. As is pointed out by Ladefoged and Johnson (2011), the velarized /l/ (the /l/ sound as in *feel*) “is not an alveolar consonant but more like some kind of back vowel (p.69)”. In order to explain the different articulatory feature between clear and dark /l/s, Sproat and Fujimura (1993) proposed a model in which they distinguished consonantal gestures from vocalic gestures.

In Sproat and Fujimura’s (1993) theory, clear /l/s belong to the consonantal gestures category whereas dark /l/s belong to the vocalic gestures category. According to their definition, consonantal gestures are attracted to syllable margins and tend to be stronger (i.e., have greater displacements) in syllable initial position and weaker in syllable final position. Vocalic gestures are attracted to syllable nuclei and tend to be weaker (i.e., have lesser displacements) in syllable initial position and stronger in syllable final position (p.305). Sproat and Fujimura pointed out that the idea behind this consonantal/vocalic gestures categorization is that universally CV structure is the basic syllable type. Consonantal gestures are typically manifested at the beginning of syllables and vocalic gestures at the end.

The assumption of the Consonantal Gestures versus Vocalic Gestures Model that open-syllable structure (CV) is favoured universally, however, is not agreed by a number of scholars (e.g., Benson, 1988; Sato, 1983; Tarone, 1987) in the field of second language

acquisition. Open syllable preference has only been found to have a minimal effect on English L2 syllable structure production. Sato (1983) conducted a study on Vietnamese English learners and found that they demonstrated the preference for closed rather than open syllables in the modification of English syllable-final consonant clusters. Benson (1988) came to the similar conclusion that open syllable preference only has a minor role in second language phonology acquisition.

Despite the disagreements on the universal preference for CV syllable structure, first language's influence on second language phonology acquisition is well recognised (Anderson, 1987; Eckman, 1991; Hansen, 2001; Tarone, 1987; Weinberger, 1987). Since CV is the dominant syllable structure in Mandarin Chinese, based on Sproat and Fujimura's model, one can reason that Mandarin Chinese speakers will favour vocalic gestures more than consonantal gestures at syllable final position.

Mandarin speakers' preference for vocalic gestures for syllable final /l/s has indeed been found to be the case. For instance, in He and Lin's studies (2004, 2005) with Mandarin speaking participants who were from China and were studying at the University of Victoria, Canada, out of a total of 944 dark /l/ tokens in the elicitation tasks, only 23 or 2.5% were produced correctly. 67.3% of all the tokens were produced as some kind of a back vowel or their diphthongized or glide variations.

2.5 Using Ultrasound in Articulatory Studies

Ultrasound imaging technique has been used widely in examining articulation process of speech (e.g., Adler-Bock, 2007; Chen, 2011; Gick, 2002; Gick et al., 2005; Hudu, 2010; Li (2010); Mielke et al., 2011; Moisik et al. (2013, in press); Stone, 1990, 1997). It can produce real-time tongue movement videos that can be used to examine the

articulatory process of word production. The two advantages of ultrasound are its fast imaging speed (60 scans/sec) and its less invasive examining process, compared with MRI or laryngoscopy.

Ultrasound, however, has some disadvantages. First, about 1 cm of the tongue tip may not be imaged because the ultrasound beam is reflected by the interface between the floor of the mouth and the air above it. Second, it is unable to image beyond a tissue/air or tissue/bone interface. Thus palate, pharyngeal wall, jaw and hyoid bones cannot be seen by ultrasound (Stone, 1990).

It is discussed above (Section 2.2) that scholars (e.g., Browman & Goldstein, 1995; Clark & Yallop, 1995; Ladefoged & Maddieson, 1996; Recasens, 2004; Wrench, 2003) held different opinions on the primary and secondary articulation features of clear and dark /l/s. In the present study, ultrasound-imaging will be used to examine (1) the tongue dorsum and tongue root configurations during the production of /l/ by native and Mandarin ESL speakers, and (2) the gestural timing of /l/ production by both groups of speakers.

Chapter 3

Method

3.1 Participants

Four Mandarin Chinese speakers (1 male and 3 females) and four native Canadian English speakers (2 males and 2 females) participated in this study. A two-page questionnaire (see Appendix 2) was administered to elicit participants' language backgrounds such as their mother tongues and their language learning experiences. Participants in this study were between the ages of twenty-three and forty-four, most of whom fell into the age group of 25-30. The four Mandarin Chinese speakers were from the same dialect area (Northern dialect) in Mainland China. The four Canadian English speakers were all born and raised on the west coast Canada.

3.2 Stimuli

To elicit speech production, twenty-four words and six mini-dialogues (see Appendix 1) were created based on He and Lin (2010, personal correspondence). The first three dialogues has the following target words with /l/ coda: *mail, bowl, bill, curl, cull, bell, meal, pull, ball, pal and pool and the following words with /l/ onsets: look, leaves, lad, lay, law, loop, lurk, low, luck, led and lit*. The target word with /l/ onset is in one of the eleven vowel contexts: /i/, /ɪ/, /e/, /ɛ/, /u/, /ʊ/, /o/, /ɔ/, /ɑ/, /ʌ/, /ɚ/, and /æ/. The target word with /l/ coda is in the same eleven vowel contexts: /i/, /ɪ/, /e/, /ɛ/, /u/, /ʊ/, /o/, /ɔ/, /ɑ/, /ʌ/, /ɚ/, and /æ/, and their onset was a bilabial /b/, /m/, or /p/. Bilabial consonants are

used to minimize the influence of the consonants to the tongue configurations of the following /l/s.

Table 3.1 gives the list of the target words in various vowel contexts with /l/ in onset and coda positions.

Vowel context	Single coda /l/	Vowel context	Single onset
/i/	meal	/i/	leaves
/ɪ/	bill	/ɪ/	lit
/e/	mail	/e/	lay
/ɛ/	bell	/ɛ/	led
/u/	pool	/u/	loop
/ʊ/	pull	/ʊ/	look
/o/	bowl	/o/	low
/ɑ/	ball	/ɑ/	law
/ʌ/	cull	/ʌ/	luck
/ɔ/	curl	/ɔ/	lurk
/æ/	pal	/æ/	lad

Table 3.1 Stimuli for single /l/ in coda and onset positions

3.3 Data Collection

Participants were recorded one at a time. First, they were instructed to read a consent form, and after signing the consent form and filling out the language background questionnaire they were given the stimuli paper with eleven onset /l/ words, eleven coda /l/ words and six mini-dialogues (see Appendix 1). They were asked to go through the stimuli paper and identify the unfamiliar words before the recording started. Most participants claimed that they knew all the words on the list. In cases where a participant did not know a certain word, a riming word was given to the participant to help him or her pronounce the word accordingly. Participants were asked to read each

word and mini dialogue three times during the recording. A total of 133 tokens were collected from each participant (66 from the word list task and 66 from the mini dialogue task). Out of the 66 tokens from each task, 33 of them were onset /l/ production (11 words repeated 3 times) and the other 33 tokens were coda /l/ production (11 words repeated 3 times).

In all recordings, target stimuli were shown in a Microsoft Power Point slide on a computer screen directly facing the participant. Participants read the word list and the mini-dialogues three times in case some frames may be not clear enough for further analysis. Before the recording, participants were instructed to practise the on-screen reading of the test stimuli.

The tongue movements during the production of the words and dialogues were collected using a GE Logiqbook E portable ultrasound machine. Midsagittal video of the tongue was recorded from a GE Logiqbook E portable ultrasound machine with an 8C-RS 5-8 MHz transducer at a standard rate of thirty frames per second. A diaphragm condenser microphone (M-Audio Lunar) was placed at about 10 cm distance from the participant's mouth. The video signal from the ultrasound machine and the audio signal from the microphone were synchronized and captured directly to the computer using Sony Vegas 8.

The ultrasound machine had an 8C-RS 5-8 MHz transducer at a standard rate of thirty frames per second (about 30 Hz). The transducer was held by participants under their chins to image the mid-sagittal region, from tongue-tip to tongue-root. Water-soluble ultrasound gel was applied to the head of the transducer and participants were asked to drink water before the start of the recording session. Those procedures were adopted to

enhance the clarity of the ultrasound images. Participants were given two to three minutes to get familiar with the equipment before each recording session.

Real time ultrasound video was transmitted directly to the computer using Adobe Premier Pro, via a Canopus audio-video mixer connected to the computer. Audio recording was done simultaneously using a microphone connected to the Canopus via a Shure dual microphone pre-amplifier.

Further measures were taken to ensure the accuracy of data collection and to avoid measurement errors. Participants' head movement was restricted using a chair with a backrest holding the participants' heads from the upper part of the neck. Previous studies (e.g., Gick et al, 2005) showed that a headrest is effective in controlling most head movements. The recording was performed in the Speech Research Laboratory of the University of Victoria.

3.4 Data Analyses

3.4.1 Acoustic measurements

The audio file collected simultaneously with the ultrasound video was used to get the formant values of the /l/ variations through Praat. F1, F2 and F3 values of the clear and dark /l/ production were extracted.

Before data analysis, tokens were extracted from the original .wav file by using a Praat script. A preliminary .TextGrid file was then automatically created to segment and label each extracted token. Once the TextGrid file together with the token's waveform and spectrogram were read to the Praat object window, the researcher then set the segmenting points based on the labelling standards described below.

Initial and final liquids were hand-labelled based on formant track. In the previous studies, researchers (Sproat & Fujimura, 1993; Cater and Local, 2007) used F2 transition and spectral discontinuity as references to locate the liquids. The present study adopted the same standard. The following two graphs demonstrate the details of this method.

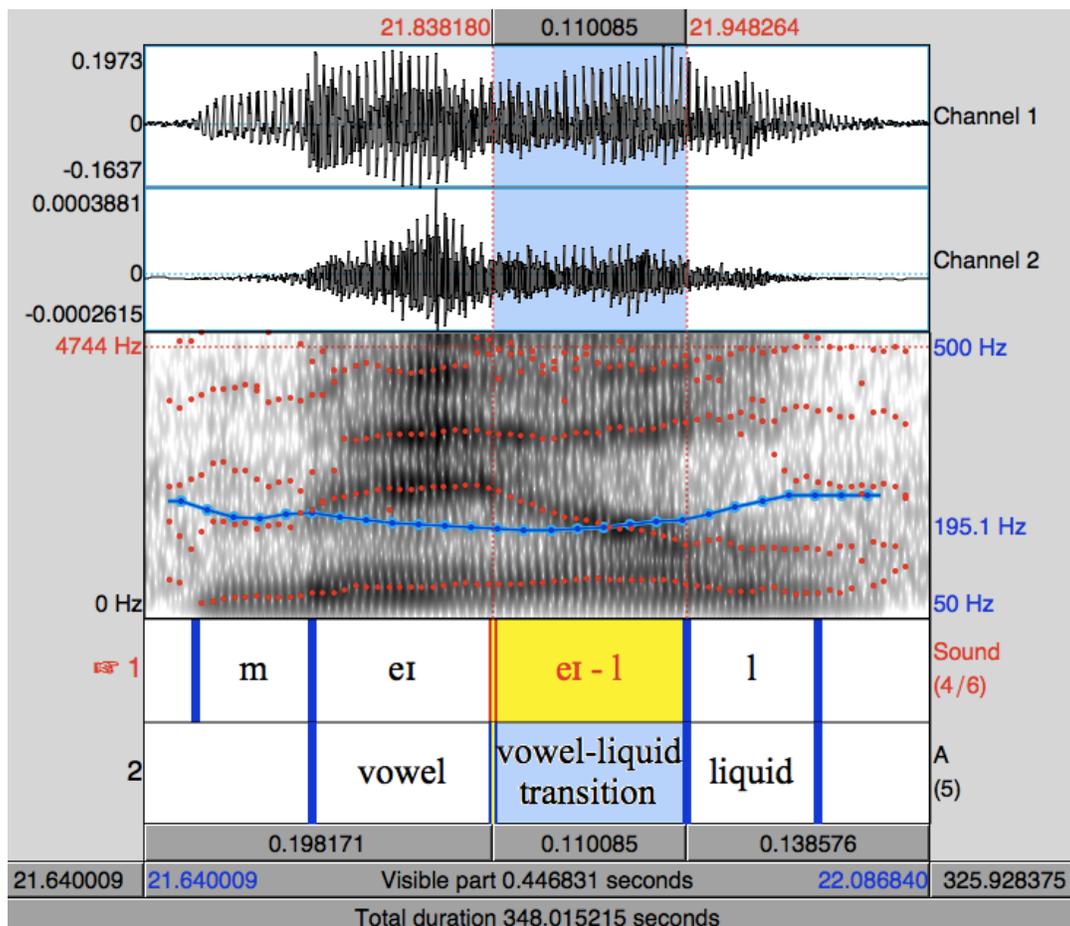


Figure 3.1 Labelling of the word “mail”

As is shown in Figure 3.1, the researcher labelled (1) the consonant before the vowel (“/m/”), (2) the start and end of the steady part of the vowel (“/ei/”), (3) the start of the F2 transition from the vowel into the liquid (“/ei-l/”), and (4) the start and end of the steady part of the liquid (“/l/”).

For onset /l/s shown in Figure 3.2, the researcher labeled (1) the start and end of the steady liquid (“/l/”), (2) the start and end of the F2 transition in and out of the liquid (“/l-er/”), and (3) the start and end of any vowel following the liquid (“/er/”).

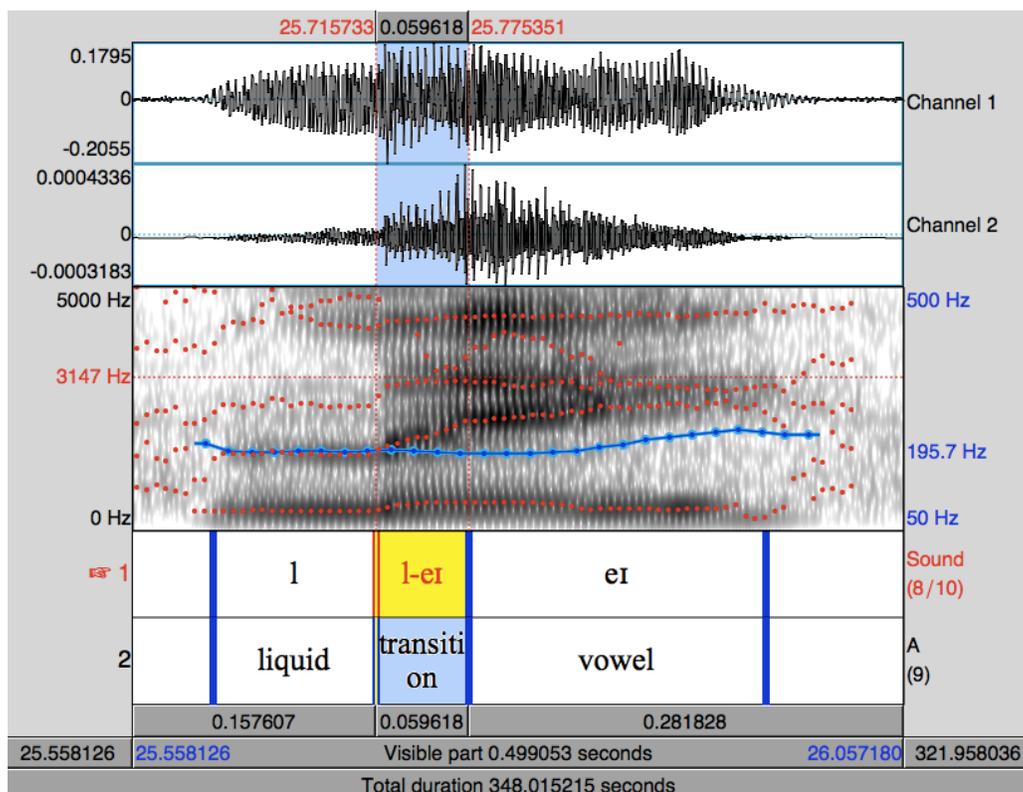


Figure 3.2 Labelling of the word “lay”

The F1/ F2/ F3 frequencies at the mid point of the labelled liquids were extracted by clicking on the “Get Formant” button in Praat. The results were visually checked again in case of any abnormality.

3.4.2 Ultrasound measurements

The ultrasound recordings were first saved as .avi files through Sony Vegas 8. Then the .avi files were converted to .mov files by launching QuickTime Player 7. Since all the participants read the stimuli at a normal speech rate, it is hard to separate the liquids from

the preceding or following vowels by just playing the videos at the original speed. In order to get the accurate start and end point of the liquids, all the recordings were reset at a three-time slower motion speed. Speech synchronization would be a good way to avoid any audio-video discrepancy, however, due to the complexity of the technique, the present study did not utilize it.

3.4.2.1 Video Conversion

After resetting the play speed of the recording, the researcher extracted and saved the liquids portion of each word by exporting the selected part whose beginning and ending part was chosen based on the researcher's listening judgements. The video clips were saved as .mov files automatically by using QuickTime Player 7. Then those selected videos were converted to a series of .jpg images at a frame rate of thirty per second. The frame rate was set at thirty because it was consistent with the imaging rate of the ultrasound machine. The software used in the conversion was Video Converter for Mac (version 3.3.9). The Video Converter for Mac generated a series of still images for each selected liquid clip and those images were numbered sequentially. For each video clip, only the image in the very middle of the image series was selected for further comparison. For each participant, forty-four images were collected for ultrasound analysis, with twenty-two of them from the word list task (11 onset /l/ tokens and 11 coda /l/ tokens) and the other twenty-two from the mini dialogue task (11 onset /l/ tokens and 11 coda /l/ tokens).

3.4.2.2 EdgeTrak Processing

After obtaining the .jpg images for all the liquids in the stimuli, including words in the word list task and in the mini-dialogue task, the researcher loaded the images to EdgeTrak (1.0.0.4), a free software program developed by researchers at the University of Maryland used to extract the tongue contour in an image. By adding and adjusting the tongue contour tracking points to the white curve in the ultrasound image and using the optimizing function in the software, the researcher extracted the (x, y) coordinates for each of the dots from the tongue contours. The detailed steps were described below.

Since EdgeTrak would only analyze a group of .jpg files if they share the same file name but with different series numbers (“onset 1 001”, “onset 1 002”, etc.), the researcher renamed the tokens with the following name-number correspondence:

Words recorded	EdgeTrak name	Words recorded	EdgeTrak name
meal	coda 001	leaves	onset 001
bill	coda 002	Lit	onset 002
mai	coda 003	lay	onset 003
bell	coda 004	led	onset 004
pool	coda 005	loop	onset 005
pull	coda 006	look	onset 006
bowl	coda 007	low	onset 007
ball	coda 008	law	onset 008
cull	coda 009	luck	onset 009
curl	coda 010	lurk	onset 010
pal	coda 011	lad	onset 011

Table 3.2 Coda and onset /l/ tokens and EdgeTrak name correspondence

Tokens from the word list and the mini dialogue tasks were processed separately, the researcher used the same EdgeTrak name even though the two image series were obtained from two elicitation tasks.

For each participant the researcher uploaded four series of images to EdgeTrak for analysis: words with /l/ onset 001-011, words with /l/ coda 001-011, dialogues with /l/ onset 001-011, and dialogues with /l/ coda 001-011.

The contour tracking dots were first set manually by putting them along the white line shown in the Figure 3.3. After optimizing the dots several times by using the “optimize” function in EdgeTrak, the researcher obtained a contour line made up of thirty red dots for each image in the series.

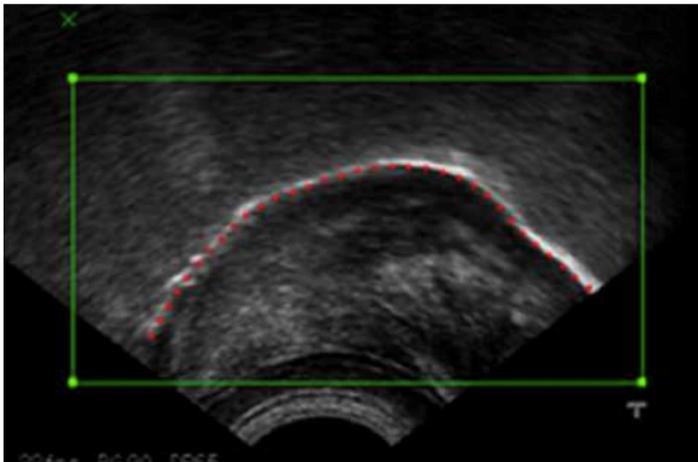


Figure 3.3 Tongue curve showing red dots from EdgeTrak.

Those tongue contour lines were then exported and saved as .con files that could be read and analyzed by Excel.

3.4.2.3 Data process in Excel

Each tongue contour extracted from EdgeTrak had two sets of values arranged in two columns in Excel: the x-axis values and the y-axis values. Since in each series of images there were 11 images, twenty-two columns of numbers with thirty rows in each column (30 dots on each tongue contour) were read to Excel for further analysis. The researcher then used the “Scatter with smooth lines” function in Excel to generate tongue contours by adding the x-axis and y-axis values to it.

The tongue contours demonstrated in this paper were not the actual tongue shape from a specific word production. Instead, each tongue contour was the average shape of all 11 production (11 vowel contexts) in a given condition (word onset or word coda /l/). The researcher averaged each of the 30 numbers (extracted from 30 tongue tracking dots from EdgeTrak) from 11 columns (11 x-axis/ y-axis values of the 11 tokens representing different vowel contexts) and obtained only two columns of values (representing only one image) for each of the four series of images (onset /l/ in word list task, coda /l/ in word list task, onset /l/ in mini dialogue task, and coda /l/ in mini dialogue task).

3.5 Statistical Data Analyses

To answer the five research questions of the present research with regards to the acoustic features of the /l/ production, the researcher conducted one-way and multiple-way ANOVA tests by using the statistical software R Version 3.0.3. The F1, F2, and F3 values extracted from the recordings of the two groups of speakers (Mandarin Chinese and Canadian English speakers) from two elicitation tasks (word list task and mini dialogue task) were used as the data in those tests.

Research Question 1 and Research Question 2 ask about the acoustic features of the onset and coda /l/s produced by Mandarin Chinese and Canadian English speakers. Using the formant values extracted from each word as the data, the researcher obtained the descriptive statistics from R for these speakers.

To address Research Question 3 about the impact of the different vowel contexts on the quality of the onset and coda /l/s produced by the two groups, the researcher used the four-way ANOVA test first to see if there was any statistical difference among the contexts. Since a significant difference ($p < 0.01$) was detected, the researcher used Multiple Comparisons of Means (Tukey Contrasts) to further locate the difference(s).

To address Research Question 4 concerning the influence of task formality on the onset and coda /l/ production, the researcher conducted the four-way ANOVA first. Since no significant difference was detected, no two-way or one-way ANOVAs were conducted.

Research Question 5 asks about the similarities and the differences between the production of Mandarin Chinese and Canadian English speakers. As done previously, a four-way ANOVA test was first conducted. Since a significant difference ($p < 0.01$) was found, the researcher continued the examination by using one-way ANOVAs.

Before each ANOVA test, a QQ plot was conducted to test if the data were normally distributed. This procedure is crucial since normal distribution of the data is the underlying assumption of the ANOVA tests. Plot of Means was also conducted by using R. Those plots generated by R can provide a graph for the factors being compared.

Chapter 4

Results

4.1 Research Question 1: /l/ production by Canadian English speakers

Since there are two tasks (word list and mini dialogue) in the experiment, the researcher will present the acoustic and articulatory analysis results for each task separately. In Section 1a, the researcher will address phonetic features of the Canadian English speakers' production from the word list task; in Section 1b, the researcher will present the results from the mini dialogue task. In each of those two sections, both acoustic results (average formant values) and the processed ultrasound images will be demonstrated.

1a. What are the acoustic and articulatory features of onset and coda /l/s produced by Canadian English speakers in the word list task?

The acoustic features of the /l/ variations can be captured by their formant values. In this study, the researcher measured and analyzed the first three formants (F1, F2, and F3) of each token. The four Canadian English speakers produced a total number of five hundred and twenty eight tokens (264 from the word list task and 264 from the mini dialogue task). In the word list task, each English speaker produced sixty-six tokens (2 kinds of /l/s \times 11 vowel contexts \times 3 repetitions). Each token corresponds with three formant values.

/l/ variations	Formant	Mean (Hz)	Standard Deviation (Hz)
Onset /l/	F1	465.04	79.28
Onset /l/	F2	1377.93	214.04
Onset /l/	F3	2498.17	191.11
Coda /l/	F1	552.12	72.74
Coda /l/	F2	1243.25	196.25
Coda /l/	F3	2637.81	312.30

Table 4.1 Descriptive statistics for formant values of /l/s produced by English speakers in word list task

Table 4.1 presents the mean frequencies and the standard deviations of the three formants (F1, F2, and F3) in two different conditions (onset and coda). Each average formant value shown above was the average of a total number of one hundred and thirty two tokens. For example, the mean F1 value of the onset /l/ produced by Canadian English speakers in the word list task was calculated by averaging one hundred and thirty two F1 values (11 vowel contexts \times 3 repetitions \times 4 speakers).

For onset /l/s that were produced by English speakers in the word list task, the mean formant values and the standard deviations are: F1 465.04 ± 79.28 Hz, F2 1377.93 ± 214.04 Hz, F3 2498.17 ± 191.11 Hz. For coda /l/s produced by English speakers in the word list task, the mean formant values and the standard deviations are: F1 552.12 ± 72.74 Hz, F2 1243.25 ± 196.25 Hz, F3 2637.81 ± 312.20 Hz.

The articulatory features of the /l/ variations will be demonstrated by showing the superimposed ultrasound images. Since male and female vocal tracts may differ the researcher did not impose all the participants' (two males and two females) tongue contours in one image. The researcher will present each of the four participants' tongue contours during the middle of their /l/ productions one at a time.

The coordination numbers of x-axis and y-axis were the values extracted by EdgeTrak. It depicts each participant's tongue configurations in two /l/ conditions. The greater the x-axis value, the more front the tongue was during the production. The smaller the y-axis value, the higher the tongue position was during /l/ production. The exact x-axis and y-axis values of one participant's cannot be compared with that of another participant because of the physiological differences across speakers. Another reason of not comparing the exact values of the coordination values is that in the present study no reference point was set during the recording. Participants could possibly have held their probe slightly different from each other.

Figure 4.1 demonstrates the tongue contours of the first female English participant. Compared with the word onset /l/, the coda /l/ was produced with the subject's tongue retracted and raised towards the back of the vocal tract. The subject's tongue tip was more forward when he or she was producing the word onset /l/ than word coda /l/s across 11 vowel contexts.

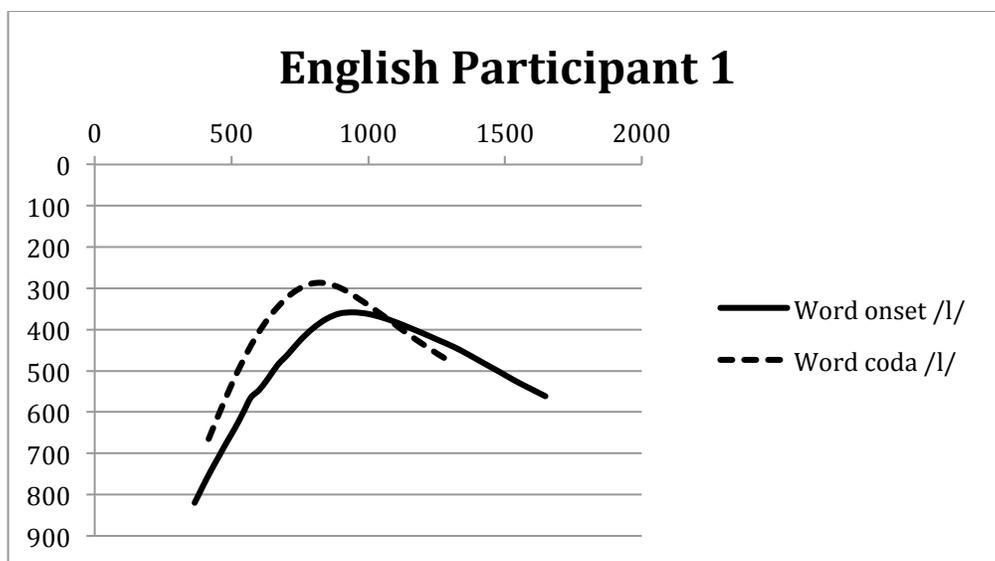


Figure 4.1 Average tongue contours of English Participant 1 in word list task

Figure 4.2 shows the average tongue contours of the second male English participant. Unlike the first participant, Participant 2's tongue is more retracted during the onset /l/ production rather than the word coda /l/ production. During the coda /l/ production, the subject's tongue is flatter and more relaxed compared with the onset /l/ tongue contour. Compared with the tongue configuration of word coda /l/, the subject's tongue position is higher and more toward the alveolar or palatal region of the vocal track during the word onset /l/ production.

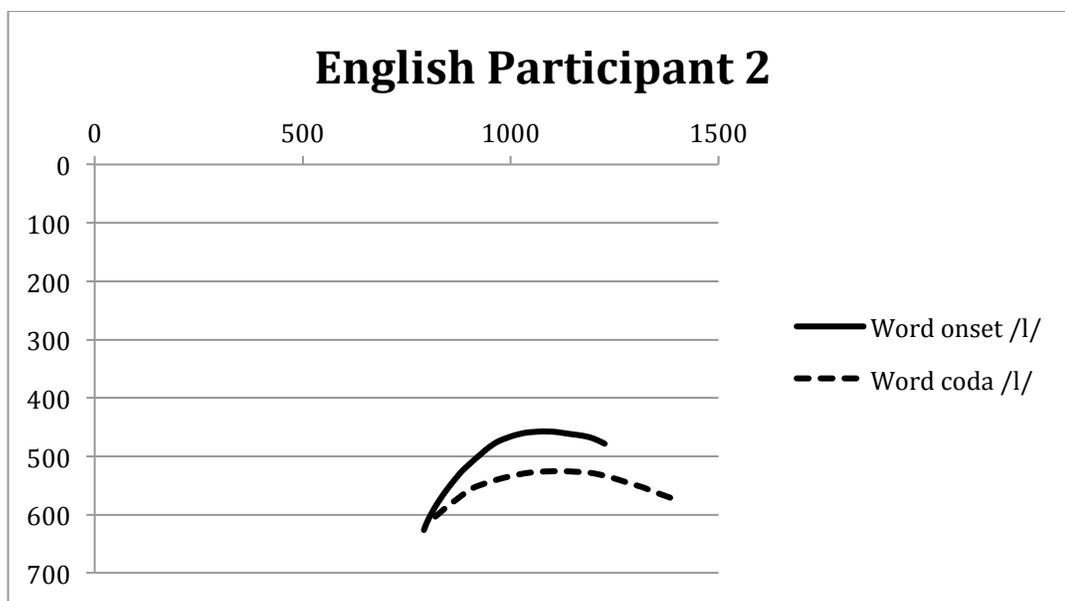


Figure 4.2 Average tongue contours of English Participant 2 in word list task

Figure 4.3 demonstrates the average tongue contours of the third male English participant. Compared with the tongue configuration of his onset /l/, the subject's tongue root is a little retracted during the coda /l/ production and the tongue height lower. The subject's tongue tip is more forward during the onset /l/ production than during the coda /l/ production.

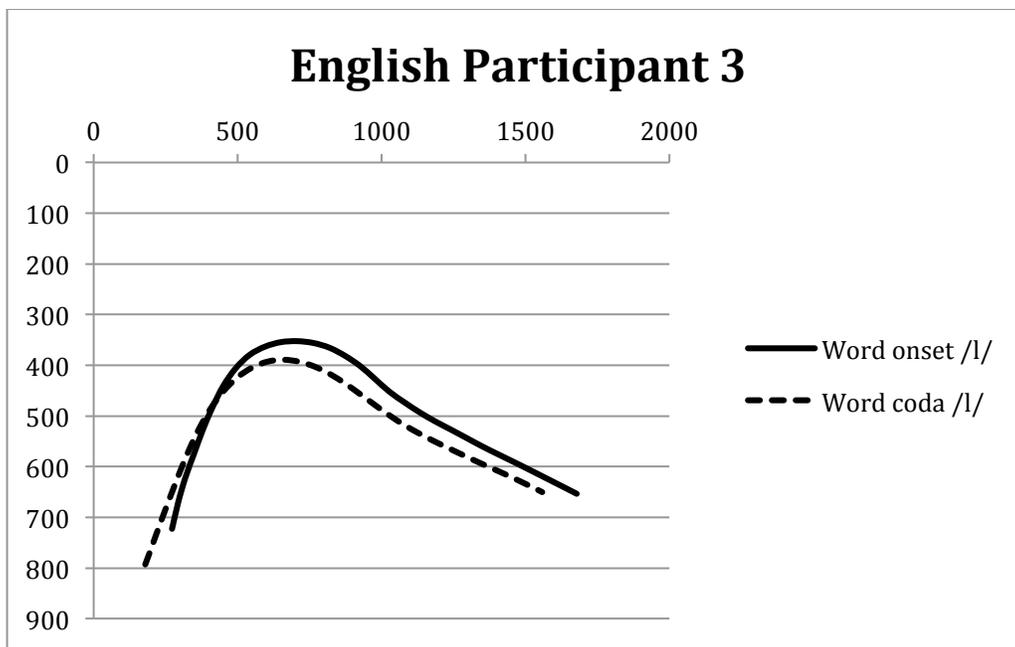


Figure 4.3 Average tongue contours of English Participant 3 in word list task

Figure 4.4 presents the fourth female Canadian English participant's average tongue shape of the word onset and coda /l/s during the word list task. The subject's tongue contours almost overlap during the onset and coda /l/ production.

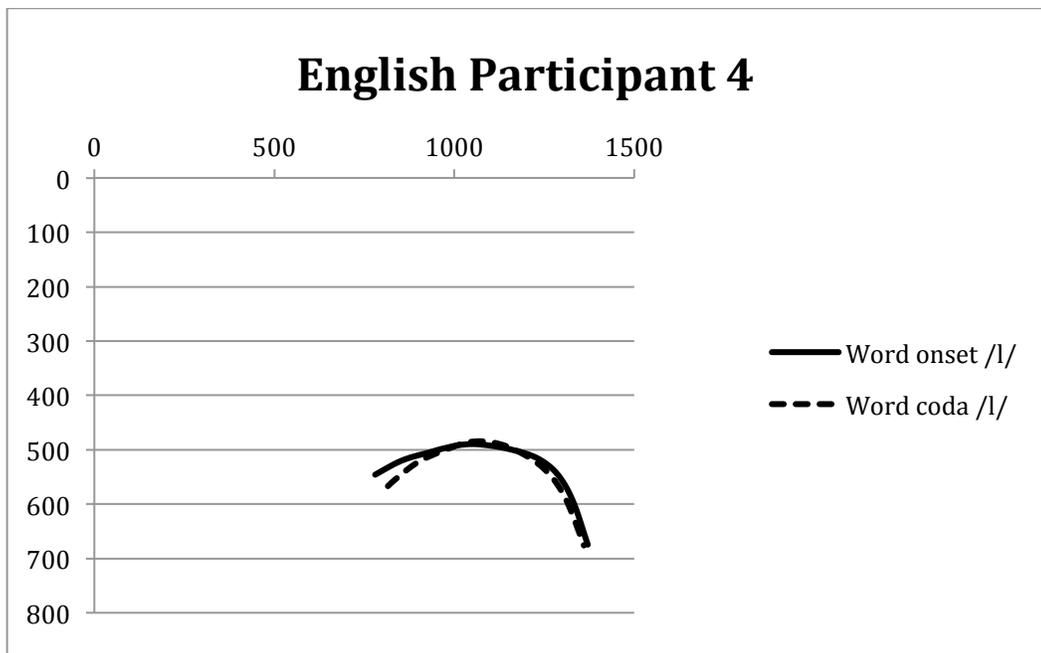


Figure 4.4 Average tongue contours of English Participant 4 in word list task

1b. What are the acoustic and articulatory features of onset and coda /l/s produced by native English speakers in the mini dialogue task?

The same descriptive statistics used above on the word list data of the English speakers are used on the dialogue data produced by the same speakers. As is shown in Table 4.2, the mean formant values and the standard deviations for onset /l/s are: F1 462.22 ± 59.09 Hz, F2 1271.69 ± 154.20 Hz, F3 2563.34 ± 221.38 Hz. For coda /l/s produced by English speakers in the mini dialogue task, the mean formant values and the standard deviations are: F1 602.30 ± 93.13 Hz, F2 1257.27 ± 173.71 Hz, F3 2743.74 ± 365.54 Hz.

/l/ variations	Formant	Mean (Hz)	Standard Deviation
onset /l/	F1	462.22	59.09
onset /l/	F2	1271.69	154.20
onset /l/	F3	2563.34	221.38
coda /l/	F1	602.30	93.13
coda /l/	F2	1257.27	173.71
coda /l/	F3	2743.74	365.54

Table 4.2 Descriptive statistics for speech data produced by English speakers in mini dialogue task

Figure 4.5 shows English Participant 1's average tongue contours during the production of onset and coda /l/s in the mini dialogue task. The participant's tongue is more retracted

in the coda condition than onset condition even though the tongue heights do not vary much. The subject's tongue tip is closer to the alveolar or palatal region during the onset /l/ production than during the coda /l/ production.

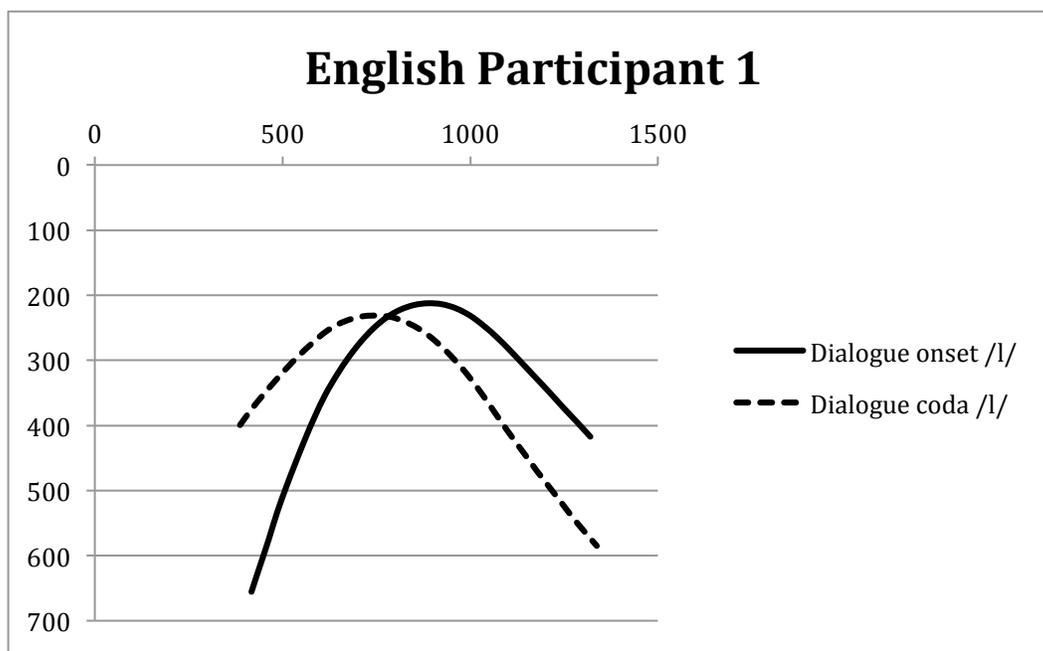


Figure 4.5 Average tongue contours of English Participant 1 in mini dialogue task

Figure 4.6 demonstrates English Participant 2's tongue contours during the onset and coda /l/ production in the mini dialogue task. The subject's average tongue shapes do not vary much between the production of the two types of /l/s. However, the subject's tongue root is slightly more retracted in the coda condition than in the onset condition. There are more tongue movement changes at the front of the vocal tract rather than at the back of it. During onset /l/ production, the subject's tongue tip is closer to the roof of the front vocal tract than in the coda condition.

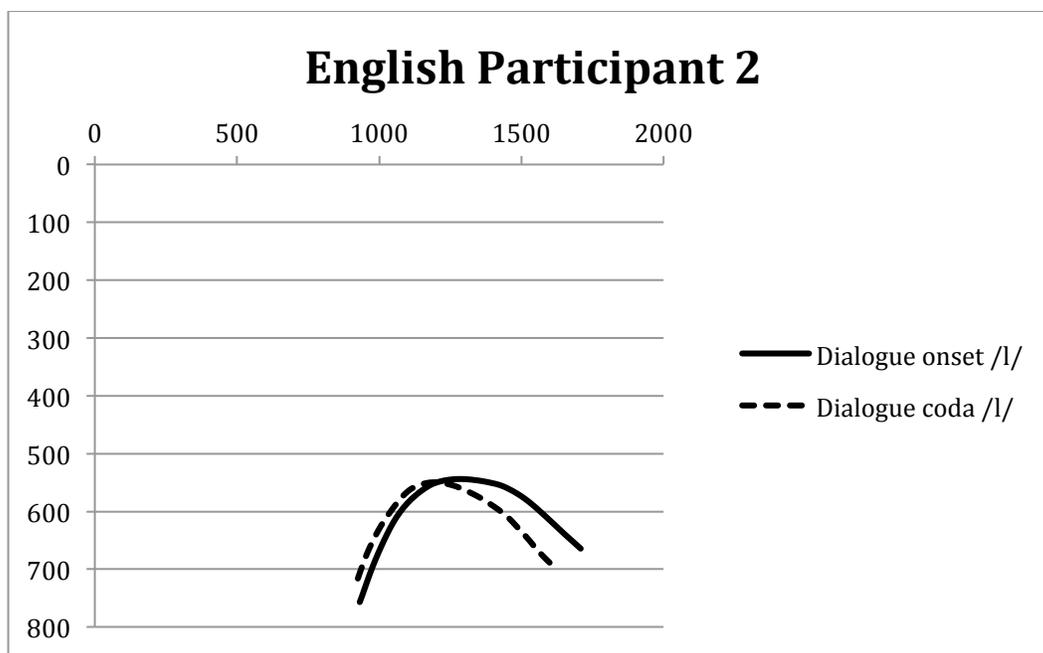


Figure 4.6 Average tongue contours of English Participant 2 in mini dialogue task

Figure 4.7 presents English Participant 3's tongue contours when he was producing the onset and coda /l/s in the mini dialogue task. During the coda /l/ production, the subject's tongue dorsum is significantly raised and retracted compared with the average tongue shape of the onset /l/ production.

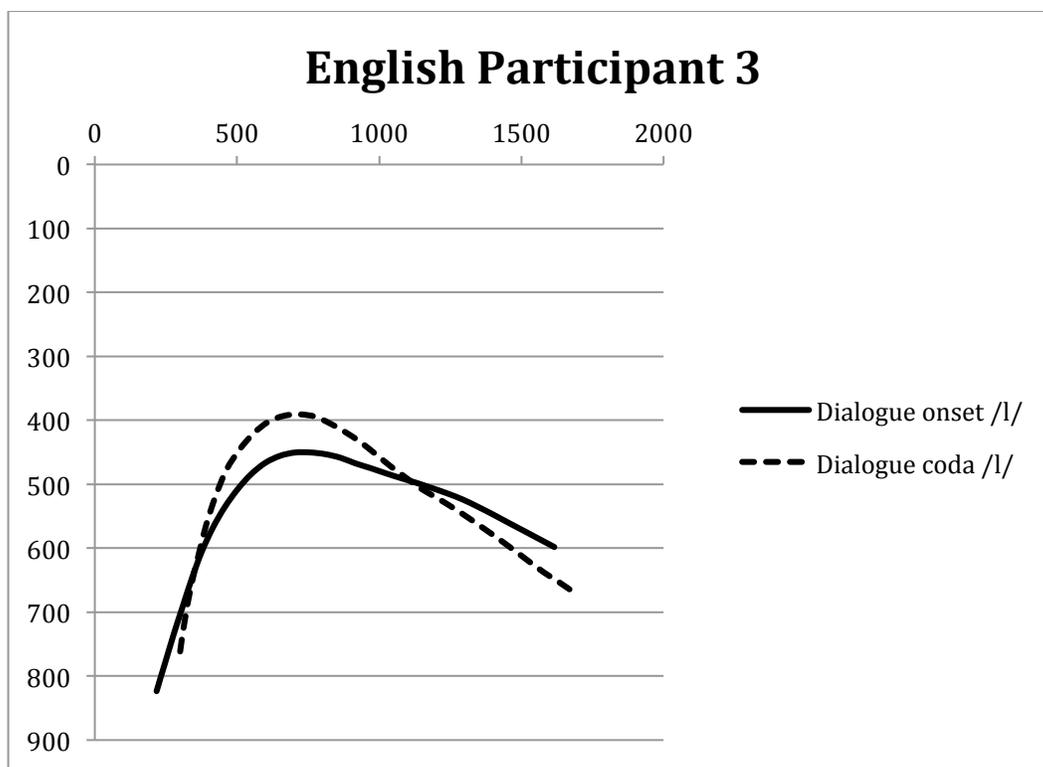


Figure 4. 7 Average tongue contours of English Participant 3 in mini dialogue task

Figure 4.8 demonstrates the tongue contours of Participant 4. The speaker's tongue body is significantly higher in the coda condition than in the onset condition. However, this may also be due to the fact that the participant moved the ultrasound probe accidentally. Each participant's head movements were not strictly restricted since it could result in discomfort and interfere with the natural production process.

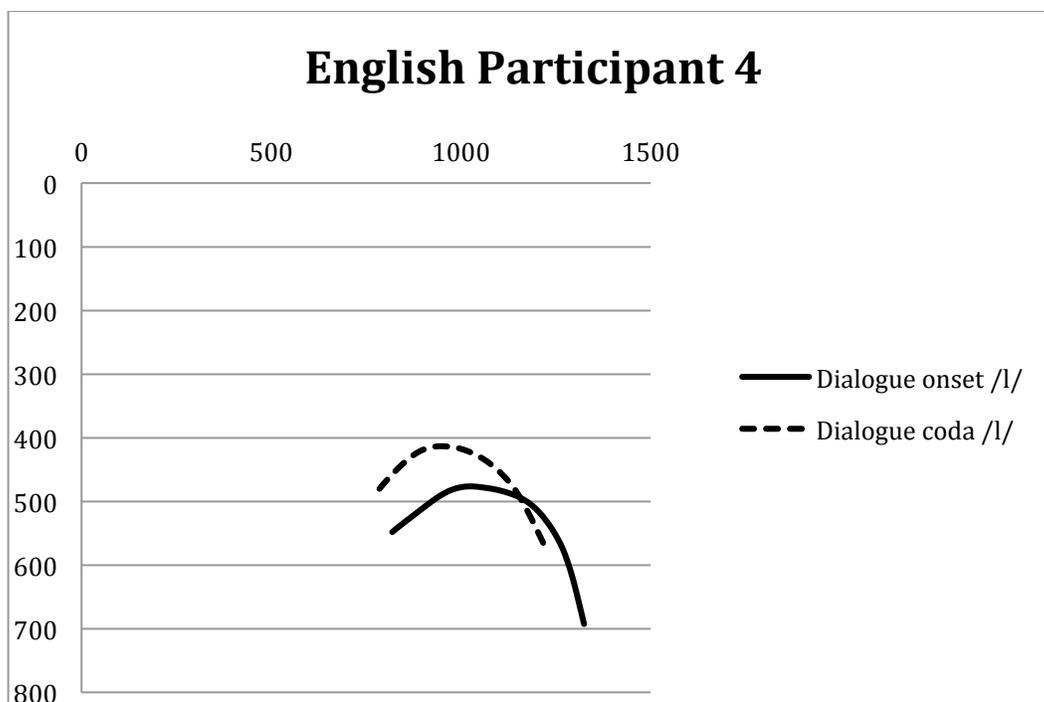


Figure 4.8 Average tongue contours of English Participant 4 in mini dialogue task

4.2 Research Question 2: /l/ production by Mandarin Chinese speakers

2a. *What are the acoustic and articulatory features of clear and dark /l/s produced by Mandarin Chinese ESL speakers in word list task?*

The same as their English counterparts, the four Mandarin Chinese speakers produced a total number of 528 tokens (264 from the word list task and 264 from the mini dialogue task). In each elicitation task, each Mandarin Chinese speaker produced 66 tokens (2 kinds of /l/s \times 11 vowel contexts \times 3 repetitions).

Table 4.3 gives the mean frequencies and the standard deviations of the three formants (F1, F2, and F3) in two different conditions (onset and coda). For example, the mean F1 value of the onset /l/ produced by Mandarin Chinese speakers in the word list task was

calculated by averaging one hundred and thirty two F1 values (11 vowel contexts \times 3 repetitions \times 4 speakers).

For onset /l/ that were produced by Mandarin Chinese speakers in word list task, the mean formant values and the standard deviations are: F1 471 ± 90.64 Hz, F2 1529.40 ± 224.15 Hz, F3 2691.86 ± 262.44 Hz. For coda /l/ produced by Mandarin Chinese speakers in word list task, the mean formant values and the standard deviations are: F1 666.59 ± 103.01 Hz, F2 1127.36 ± 158.05 Hz, F3 2653.69 ± 297.38 Hz.

/l/ variations	Formant	Mean (Hz)	Standard Deviation
onset /l/	F1	471.75	90.64
onset /l/	F2	1529.40	224.15
onset /l/	F3	2691.86	262.44
coda /l/	F1	666.59	103.01
coda /l/	F2	1127.36	158.05
coda /l/	F3	2653.69	297.38

Table 4.3 Descriptive statistics for speech data produced by Mandarin Chinese speakers in the word list task

Figure 4.9 demonstrates the average tongue contours of female Mandarin Chinese Participant 1. The subject's tongue is more retracted in the coda condition than in the onset condition. The subject's tongue tip is more towards the alveolar or the palatal region of the vocal tract in onset than coda condition.

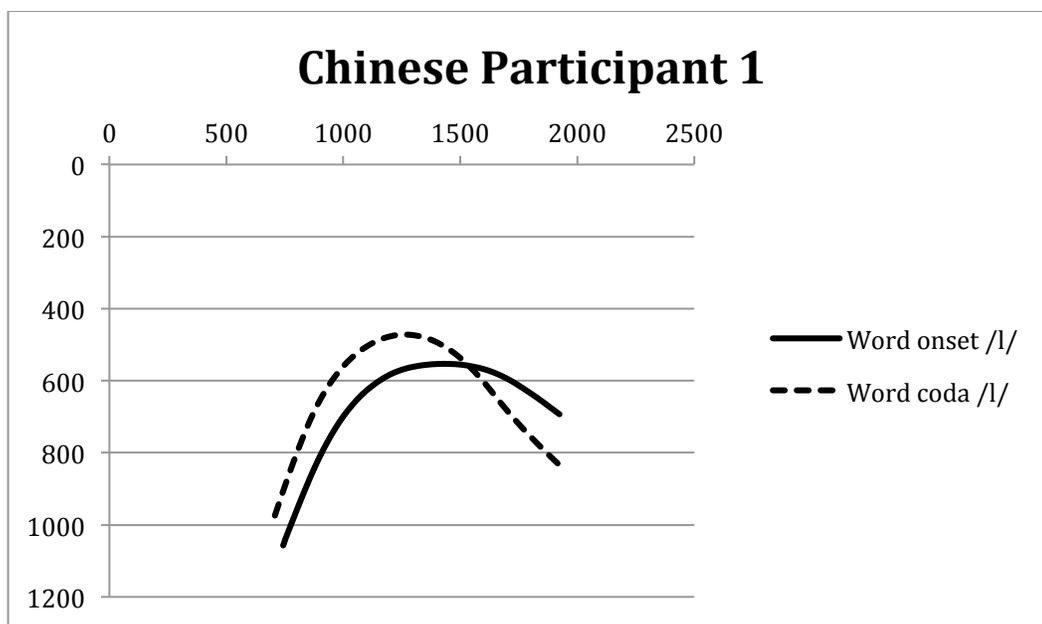


Figure 4.9 Average tongue contours of Chinese Participant 1 in word list task

Figure 4.10 shows the tongue images of male Chinese Participant 2. Consistent with the first Chinese participant, the subject raises his tongue body towards the velar region during the coda /l/ production. The subject's tongue tip reaches closer to the front part of the vocal tract in the onset than coda condition.

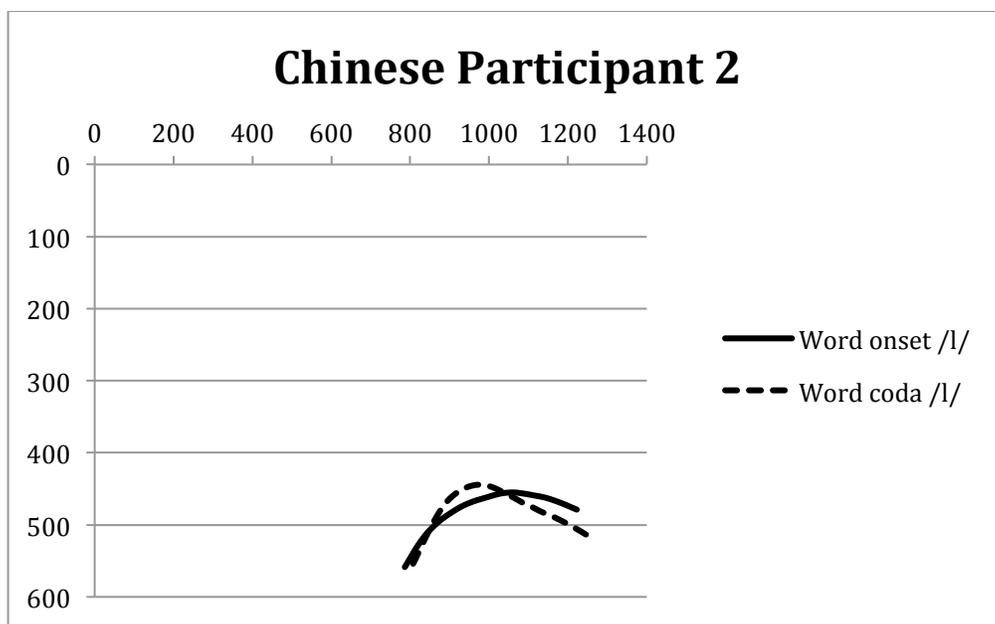


Figure 4.10 Average tongue contours of Chinese Participant 2 in word list task

Figure 4.11 illustrates the average tongue contours of female Chinese Participant 3. The subject's tongue root retraction during the coda /l/ production is shown in the Figure. As is shown in Figure 4.11, the participant raises her tongue tip dramatically during her onset /l/ production.

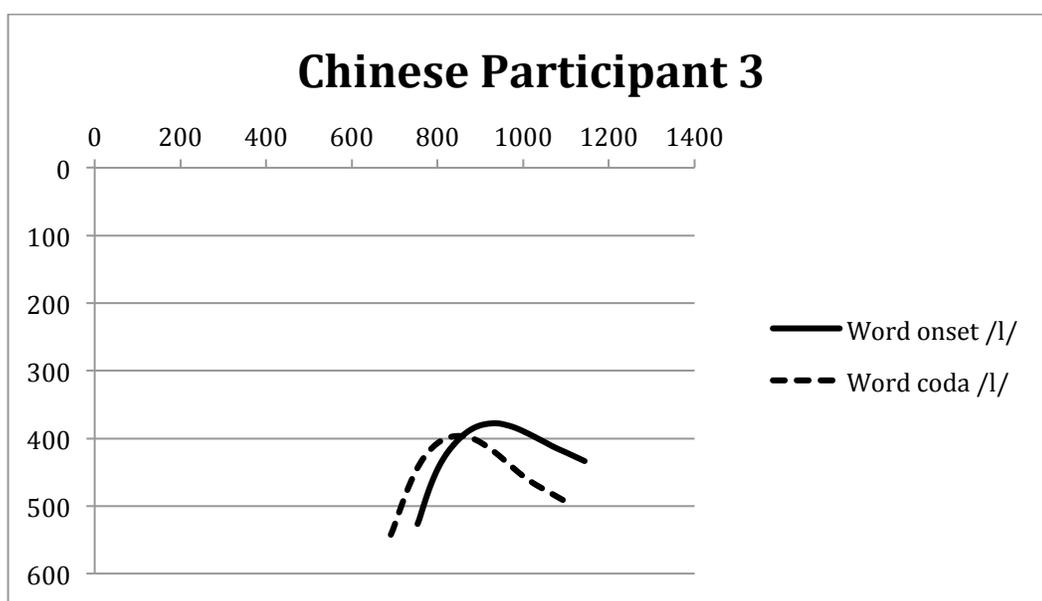


Figure 4.11 Average tongue contours of Chinese Participant 3 in word list task

Figure 4.12 presents female Chinese Participant 4's average tongue contours. The subject retracts her tongue root and raises her tongue body towards the back part of the vocal tract. She also raises her tongue tip towards the alveolar region of the vocal tract during the onset /l/ production.

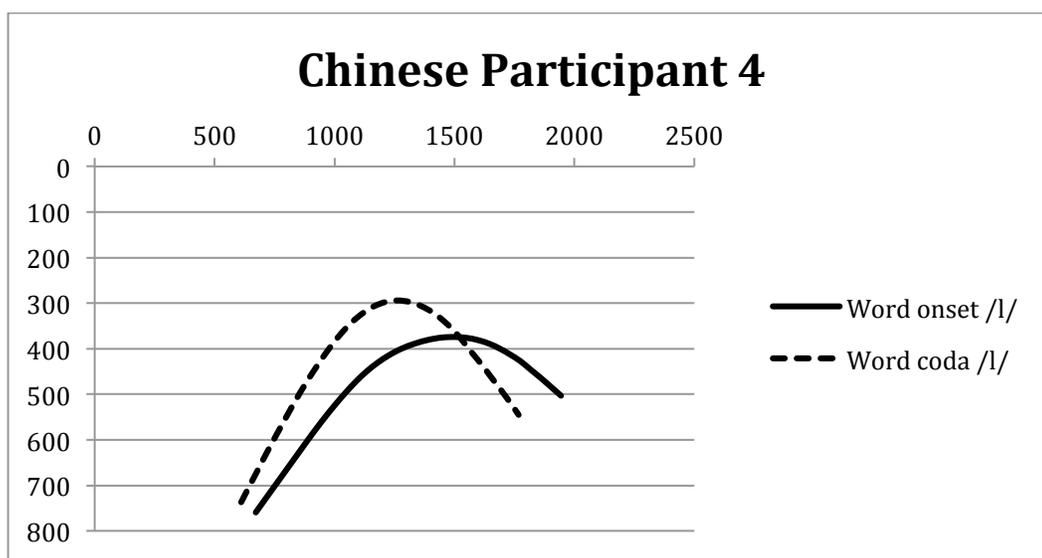


Figure 4.12 Average tongue contours of Chinese Participant 4 in word list task

2b. What are the acoustic and articulatory features of onset and coda /l/s produced by Mandarin Chinese ESL speakers in mini dialogue task?

The following data analysis is presented to address the question of the acoustic and articulatory features of the /l/ variations produced by Mandarin Chinese speakers in the mini dialogue task. As is shown in Table 4.4, the mean formant values and the standard deviations for onset /l/s in the mini dialogue task are: F1 464.74 ± 87.67 Hz, F2 1416.16

± 179.58 Hz, F3 2632.24 ± 253.67 Hz. For coda /l/s produced by Mandarin Chinese speakers in the mini dialogue task, the mean formant values and the standard deviations are: F1 640.16 ± 105.63 Hz, F2 1162.30 ± 169.55 Hz, F3 2577.77 ± 292.77 Hz.

/l/ variations	Formant	Mean (Hz)	Standard Deviation
onset /l/	F1	464.74	87.67
onset /l/	F2	1416.16	179.58
onset /l/	F3	2632.24	253.67
coda /l/	F1	640.16	105.63
coda /l/	F2	1162.30	169.55
coda /l/	F3	2577.77	292.77

Table 4.4 Descriptive statistics for speech data produced by Mandarin Chinese speakers in mini dialogue task

Figure 4.13 illustrates the average tongue contours of Chinese Participant 1 during the mini dialogue recordings. No tongue root retraction is observed during the participant's coda /l/ production, although the subject does raise her tongue body towards the palatal or velar region of the vocal tract. The subject's tongue tip shapes do not vary much in the two /l/ conditions.

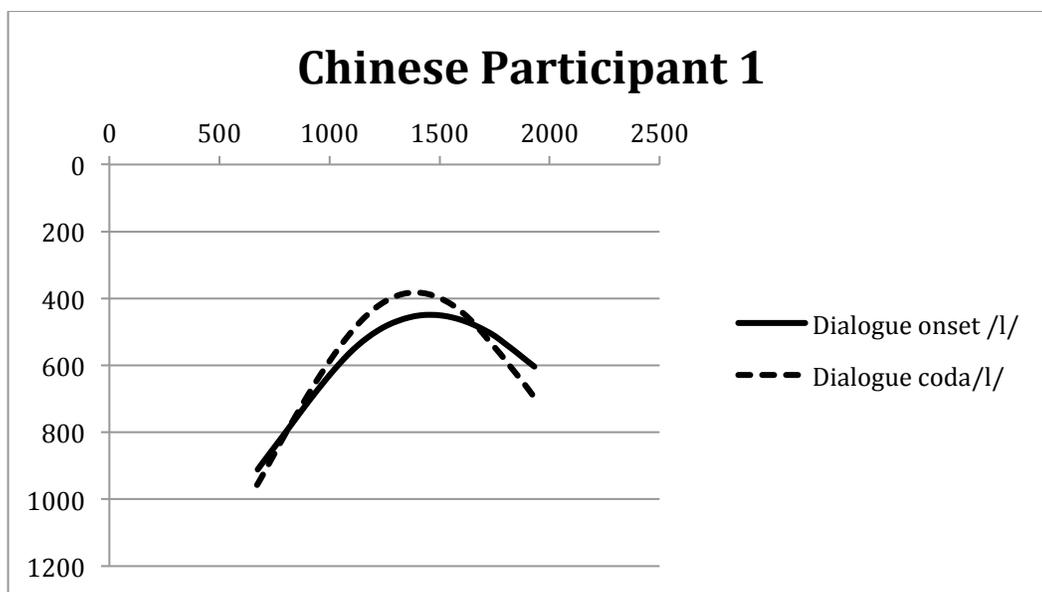


Figure 4.13 Average tongue contours of Chinese Participant 1 in mini dialogue task

The front parts of Chinese Participant 2's onset and coda /l/ tongue shape vary most prominently among all four Chinese subjects (Figure 4.14). During onset /l/ production, the participant has a smooth tongue contour and his tongue tip is more forward to the alveolar or the palatal region of the vocal tract than in the coda condition. The subject lowers his the tongue body during the coda /l/ production, however, no clear tongue root retraction is found during the process.

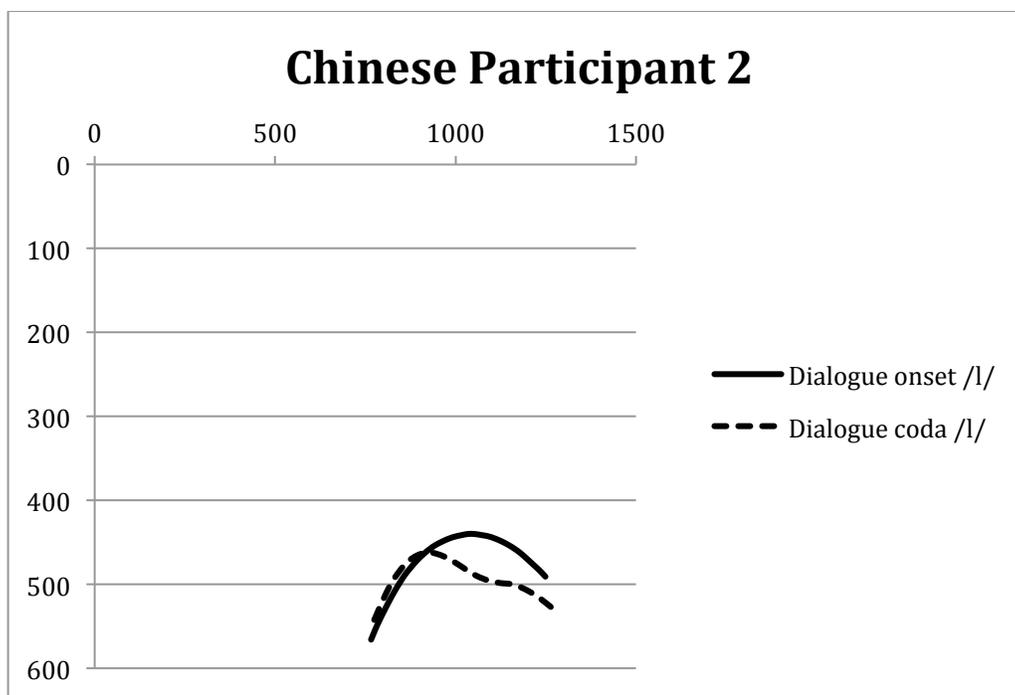


Figure 4.14 Average tongue contours of Chinese Participant 2 in mini dialogue task

As is shown in Figure 4.15, Chinese Participant 3 retracts her tongue root during the coda /l/ production. The subject's tongue body is also raised toward the back of the vocal tract in coda condition. However, no obvious tongue tip forwardness is observed during her onset /l/ production.

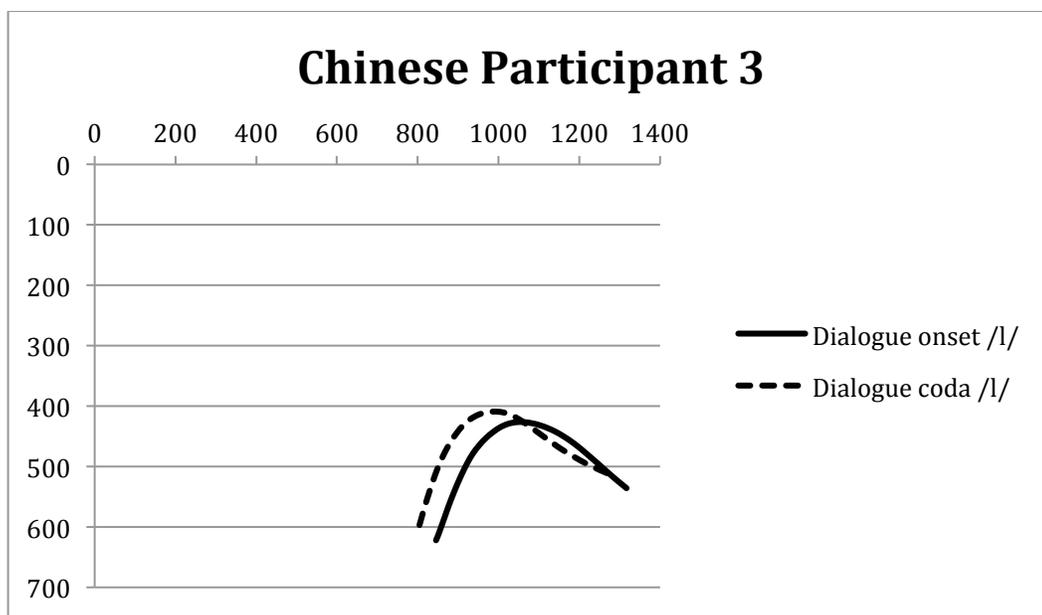


Figure 4.15 Average tongue contours of Chinese Participant 3 in mini dialogue task

Figure 4.16 demonstrates Chinese Participant 4's average tongue contours. Overall, the participant's tongue shapes do not vary much in the two /l/ conditions. The subject raises her tongue body slightly more in the coda condition than in the onset condition.

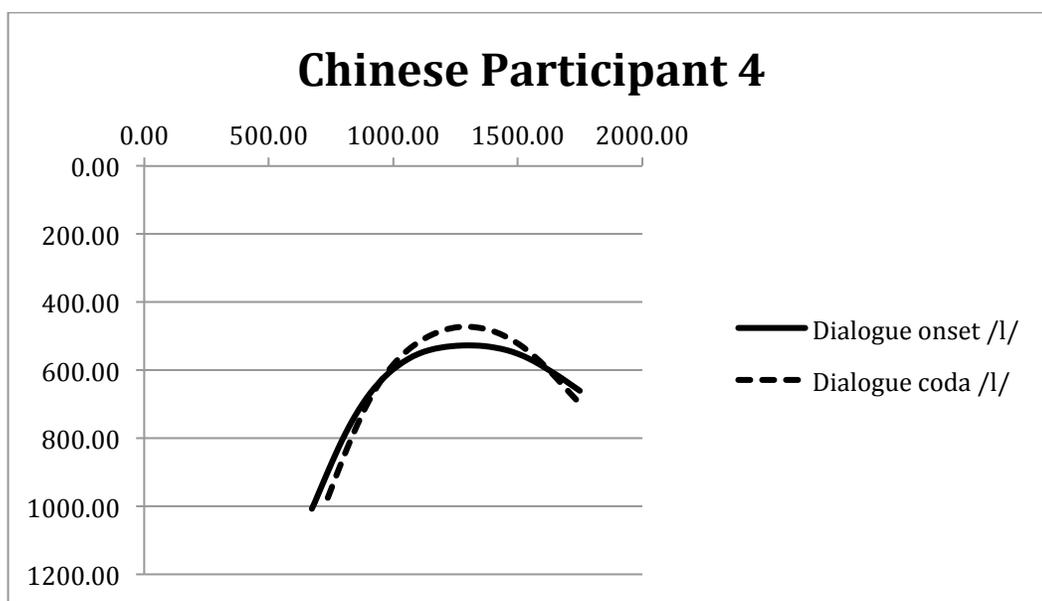


Figure 4.16 Average tongue contours of Chinese Participant 4 in mini dialogue task

4.3 Research Question 3: Vowel Contexts

3a. Do vowel contexts have an impact on the acoustic features of /l/ variations with regards to F1?

The researcher first used R to conduct the QQ Plot test to see if the data were normally distributed. As is shown in the figure below, most of the black curve consisting of numbers of black dots (each of which represents a formant value from the data pool) lies within the space closed by the red dashes, which indicates that the F1 data were normally distributed.

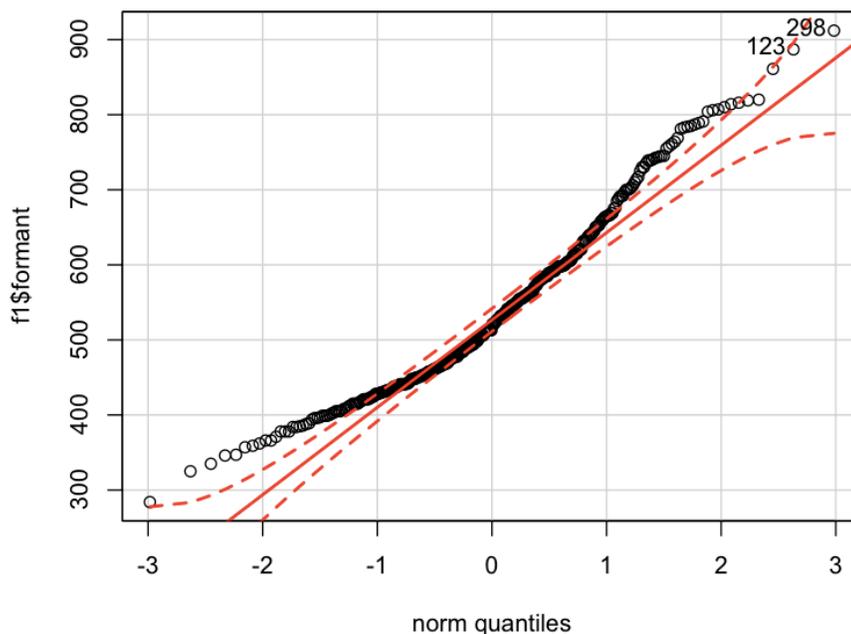


Figure 4.17 Normal distribution test (QQ Plot) for F1

After the distribution test (described above), the researcher conducted the four-way ANOVA test to see if there was any significant difference between any vowel pairs with

regards to F1. As is shown in Table 4.5, the p-value of the first response factor “Vowel” is smaller than 0.001, which indicates that there is a very significant difference between all of the two vowel pairs. The researcher then conducted the Multiple Comparisons of Means (Tukey Contrasts) to locate the specific place of difference.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Vowel	10	5.9127	<0.0001
Group: Vowel	10	1.2708	=0.2470
Types: Vowel	10	1.5911	=0.1091
Task: Vowel	10	0.4744	=0.9058
Group: Types: Vowel	10	5.0607	<0.05
Group: Task: Vowel	10	1.9365	<0.05
Types: Task: Vowel	10	0.6396	=0.7792
Group: Types: Task: Vowel	10	0.2950	=0.9819

Table 4.5 Four-way ANOVA test results for vowel context analysis (F1)

The Multiple Comparisons of Means (Tukey Contrasts) compared 55 ($\sum_2 \binom{11}{2}$) pairs of vowel contexts (/i/-/ɪ/, /i/-/e/, /i/-/ɛ/, .../ə/-/æ/). Out of 55 comparison pairs, only 3 of them had significant differences. The pairs with significant differences were listed below in Table 4.6.

Response	<i>Estimated Std. Error</i>	<i>t value</i>	<i>p</i>
/æ/ - /u/	101.2812	3.528	<0.05
/æ/ - /ʊ/	109.0000	3.797	<0.01

/æ/ - /ǽ/	102.0000	3.553	<0.05
-----------	----------	-------	-------

Table 4.6 Tukey test results for vowel context analysis (F1)

The researcher used R to plot the mean F1 values for each of the vowel context. The vowel context-number correspondence is shown in Table 4.7.

Vowel	Corresponding number
/i/	1
/ɪ/	2
/e/	3
/ɛ/	4
/u/	5
/ʊ/	6
/o/	7
/ɑ/	8
/ʌ/	9
/ǽ/	10
/æ/	11

Table 4.7 vowel – number correspondence

As is illustrated in Figure 4.18, both Mandarin Chinese and Canadian English speakers tend to have higher F1 values when they were producing vowels in the context /ɛ/, context /ɑ/ and context /æ/. Regardless of the types of /l/s that are produced, the general tendency of F1 changes across vowel contexts remains the same.

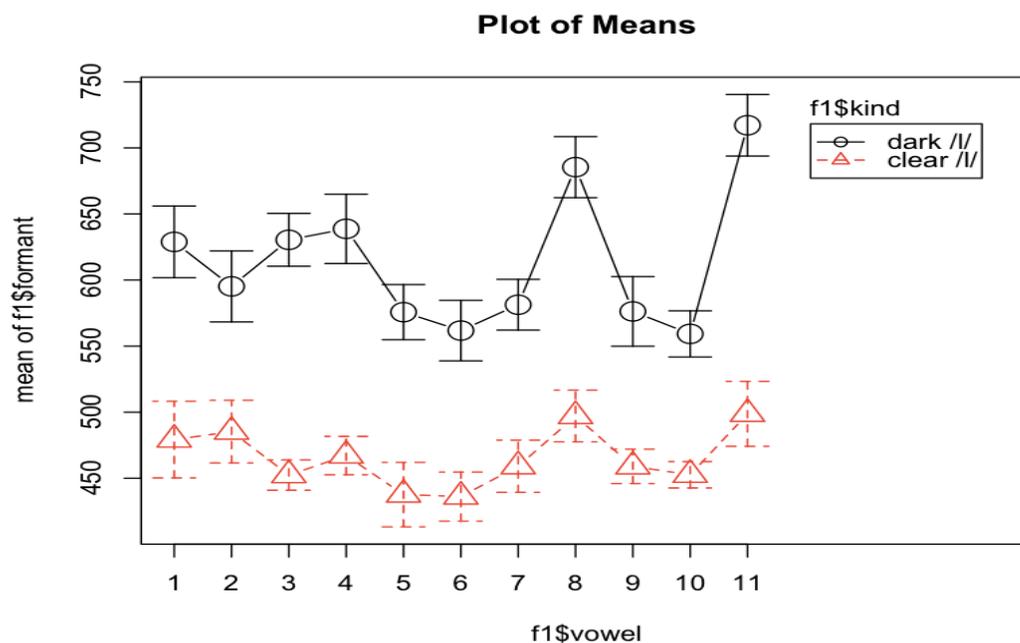


Figure 4.18 vowel contexts and /l/ variations (F1)

Across the 11 vowel contexts, Mandarin Chinese speakers have an overall higher formant frequency value than their English counterparts (Figure 4.19). For both Mandarin Chinese and English speakers, the mean F1 values are higher in the following vowel contexts: vowel / ϵ /, / α /, and / æ /.

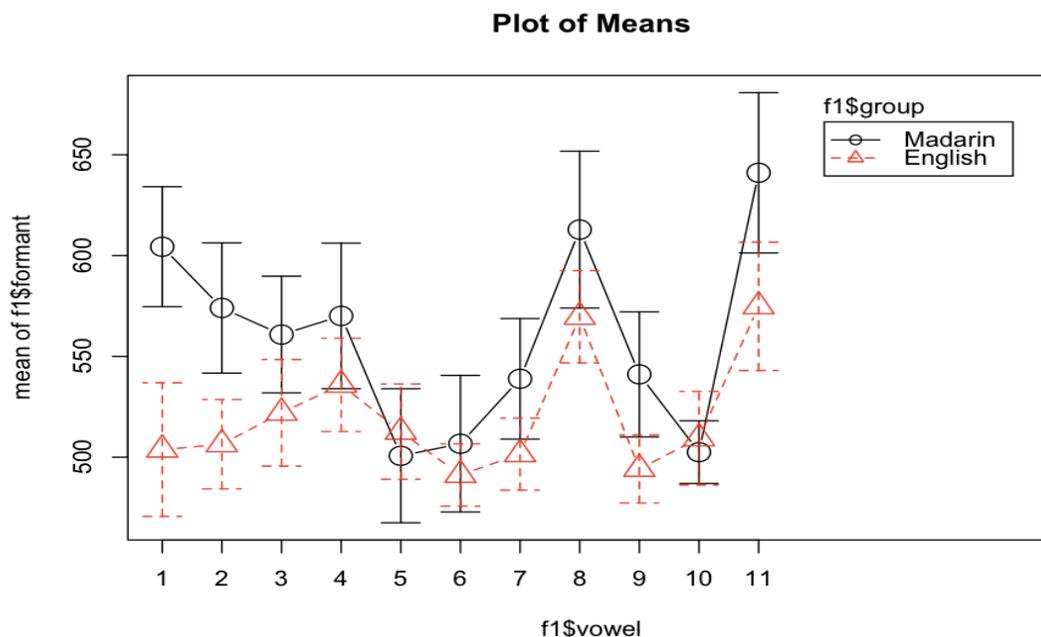
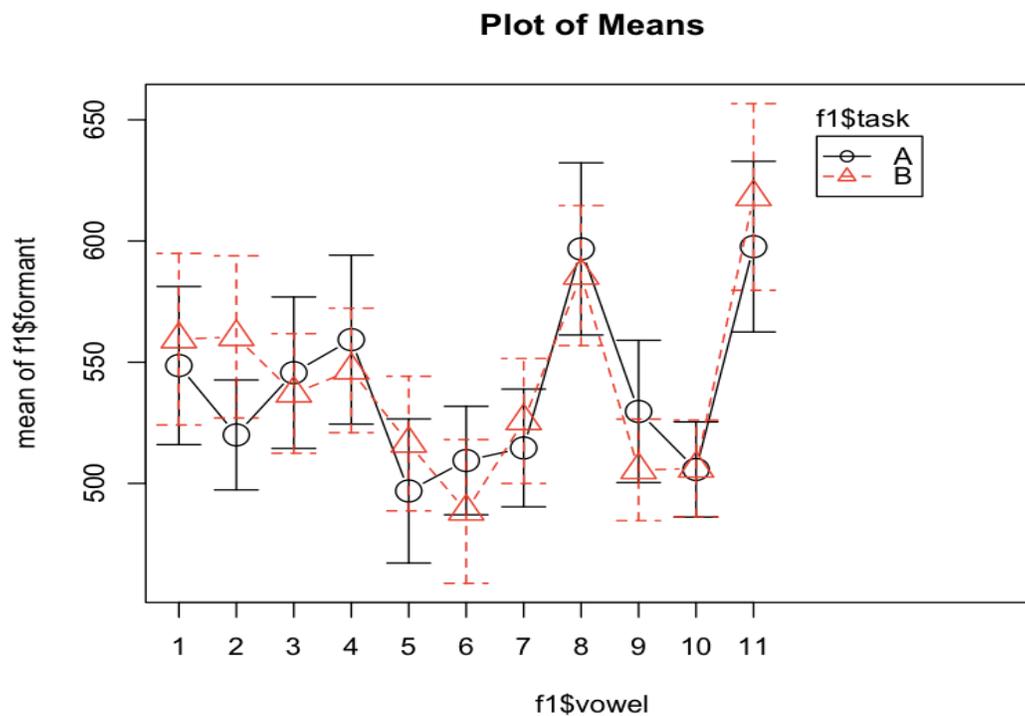


Figure 4.19 Vowel contexts and groups of speakers (mean F1)

As is shown in Figure 4.20, the F1 values do not vary much in the two types of elicitation tasks. All three Figures in this section (Figure 4.18, Figure 4.19, and Figure 4.20) demonstrate the similar “W” shaped curves regardless of the types of the /l/s (Figure 4.18), the groups of speakers (Figure 4.19), and the nature of the task (Figure 4.20). Even though the “W” shaped curve may move upwards (indicating a higher F1) or downwards (indicating a lower F1) a slightly, depending on the factor levels (two types of /l/s, two groups of speakers, and two elicitation tasks) that are being analyzed, the overall shape remains unchanged.



Note: “Task A” is the word list task; “Task B” is the mini dialogue task.

Figure 4.20 Vowel contexts and task formalities (mean F1)

3b. Do vowel contexts have an impact on the acoustic features of the /l/ variations with regards to F2?

The F2 data is normally distributed as the black curve shown in Figure 4.21 lines within the red dashed space plotted by R. After the QQ Plot test, the researcher conducted the four-way ANOVA test to see if there was any significant difference between any vowel pairs.

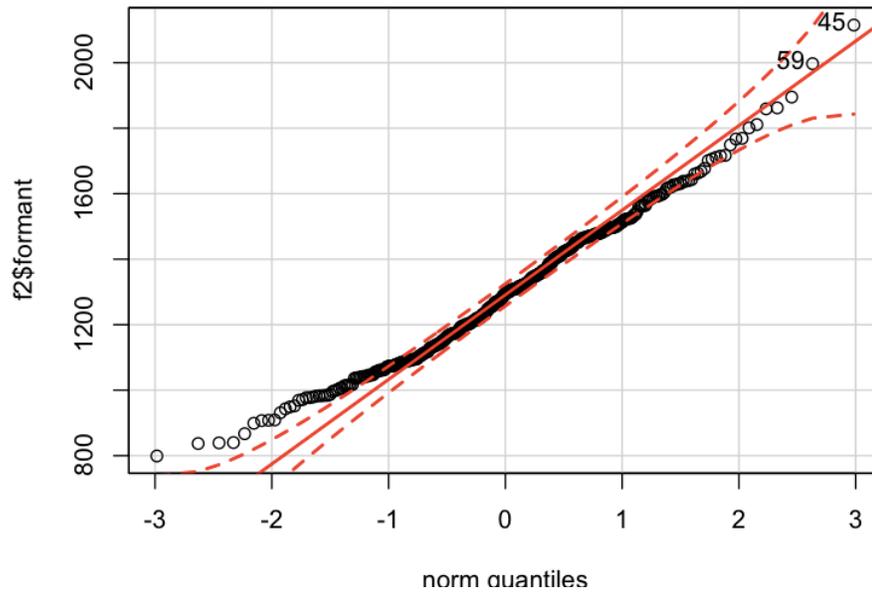


Figure 4.21 Normal distribution test (QQ Plot) for F2

As is shown in Table 4.8, the p-value of the first response factor “Vowel” is smaller than 0.01, which indicates that there is a very significant difference between any of the two vowel pairs with regards to F2. The researcher then conducted the Multiple Comparisons of Means (shown in Table 7) to locate the specific place of difference.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Vowel	10	2.4195	<0.01
Group: Vowel	10	1.7181	=0.0767
Types: Vowel	10	0.9564	=0.4820
Task: Vowel	10	0.2360	=0.9924
Group: Types: Vowel	10	0.1229	=0.7261
Group: Task: Vowel	10	0.8747	=0.5574

Types: Task: Vowel	10	0.3154	=0.9767
Group: Types: Task: Vowel	10	0.6279	=0.7895

Table 4.8 Four-way ANOVA test results for vowel context analysis (F2)

As is shown in Table 4.9, only one pair of significant difference ($p < 0.05$) is identified: the /i/ - /a/ vowel pair.

Response	<i>Estimated Std. Error</i>	<i>t value</i>	<i>p</i>
/i/ - /a/	-181.719	-3.300	<0.05

Table 4.9. Tukey test results for vowel contexts (F2)

Figure 4.22 demonstrates the average F2 value of each of the /l/ variations in different vowel contexts. Onset /l/s had higher F2 values than the coda /l/s in general. Onset /l/ in the vowel context /i/ has the highest F2 value and in vowel context /a/ it has the lowest F2 value.

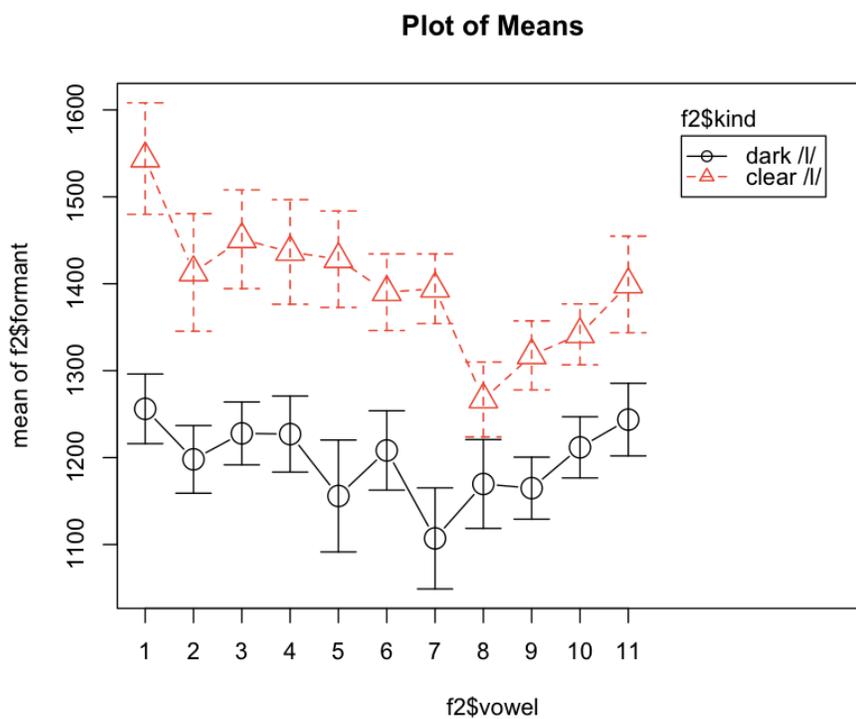


Figure 4.22 Vowel contexts and /l/ variations (F2)

Both Mandarin Chinese and English speakers have similar F2 values across vowel contexts (Figure 4.23). In the vowel context / ϵ /, Mandarin Chinese speakers produce the /l/ variations with higher F2 values, whereas in the vowel context / α / their productions have lower F2 values compared with that of the Canadian English speakers.

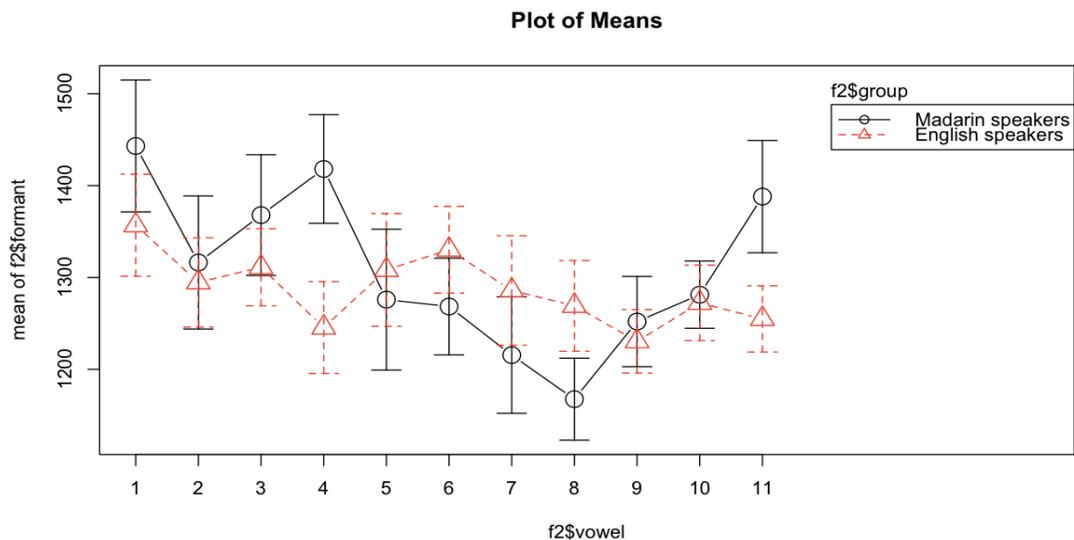


Figure 4.23 Vowel contexts and groups of speakers (mean F2)

There is not much difference between the /l/ production in the word list task and the mini dialogue task (shown in Figure 4.24). The three Figures in this section (Figure 4.22, Figure 4.23, and Figure 4.24) confirm the same findings of the previous observation: the formant values of the /l/ production have little to do with the types of variations (onset or coda /l/), the group of speakers (Mandarin Chinese speakers or Canadian English speakers), or the nature of the tasks (word list task or mini dialogue task). The curves from different Figures all share the same shape (a flat “v” shape).

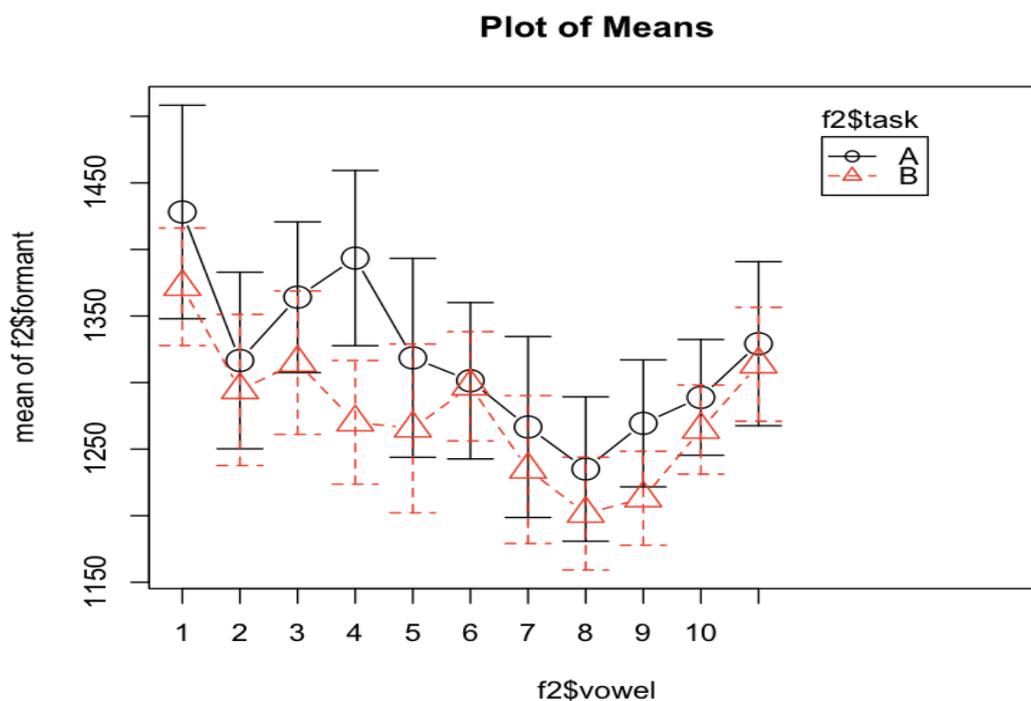


Figure 4.24 Vowel contexts and task formalities (mean F2)

3c. Do vowel contexts have an impact on the acoustic features of the /l/ variations with regards to F3?

The data for F3 analysis are normally distributed since most of the black curve representing the distribution of the data lies within the red space closed by red dashes (Figure 4.25).

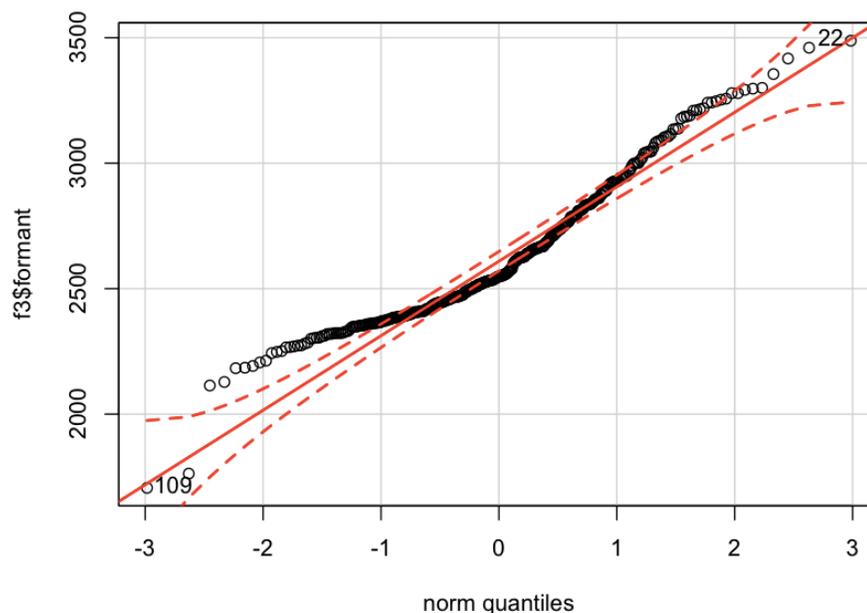


Figure 4.25 Normal distribution test (QQ Plot) for F3

After the distribution test (QQ Plot), the researcher conducted the four-way ANOVA test to see if there was any significant difference between any vowel pairs with regards to F3. As is shown in Table 4.10, the p-value of the first response factor “Vowel” is greater than 0.05, which indicates that there is no significant difference between any of the two vowel pairs. Therefore no further test (Multiple Comparisons of Means) was conducted.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Vowel	10	1.3717	=0.1933
Group: Vowel	10	0.2902	=0.9830
Types: Vowel	10	0.2520	=0.9901
Task: Vowel	10	1.1115	=0.3535

Group: Types: Vowel	10	0.1922	=0.6614
Group: Task: Vowel	10	0.5618	=0.8443
Types: Task: Vowel	10	0.3093	=0.9784
Group: Types: Task: Vowel	10	0.3430	=0.9684

Table 4.10 Four-way ANOVA test results for vowel context analysis (F3)

As is shown in Figure 4.26, coda /l/s have slightly higher F3 than onset /l/s but the difference is small. The F3 values are almost constant regardless of the vowel contexts except for the vowel context 10 (/æ/) where the F3 value is really low compared with the other conditions.

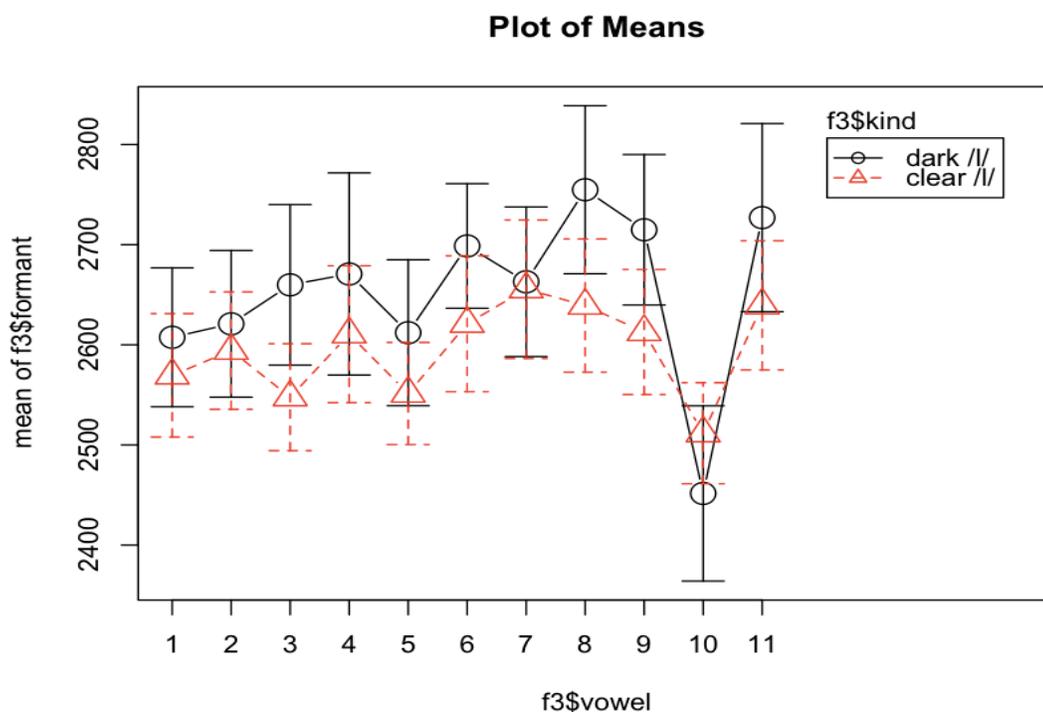


Figure 4.26 Vowel contexts and /l/ variations (mean F3)

There is little difference in F3 values between the Mandarin Chinese speakers and the Canadian English speakers (Figure 4.27). Except for the vowel context /ə/, all the other productions have relatively constant F3 values.

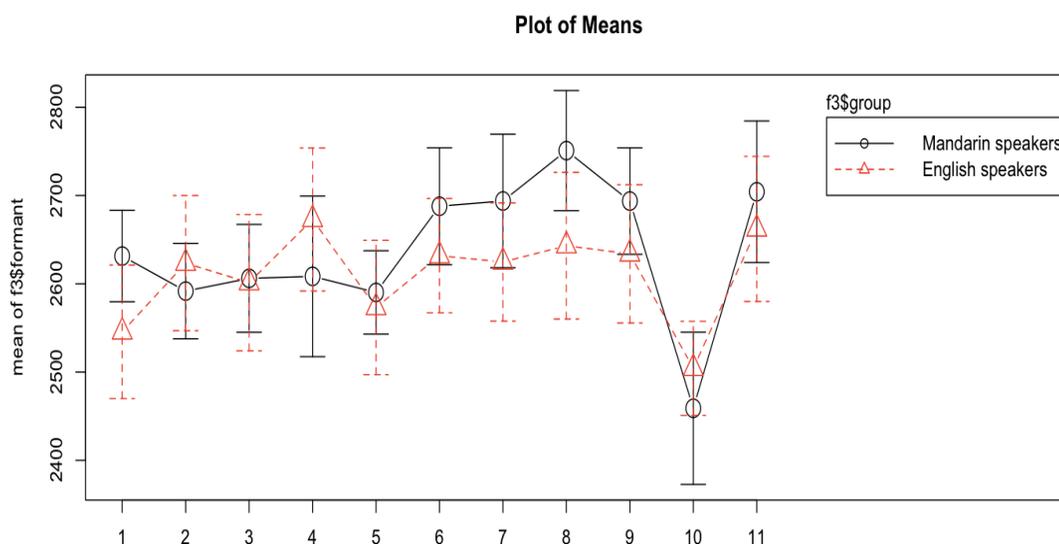


Figure 4.27 Vowel contexts and groups of speakers (mean F3)

As is demonstrated in Figure 4.28, the two elicitation tasks vary little with regards to F3 formants. Consistent with the results shown above (Figure 4.26 and Figure 4.27), the F3 value drops considerably in the vowel context /ə/.

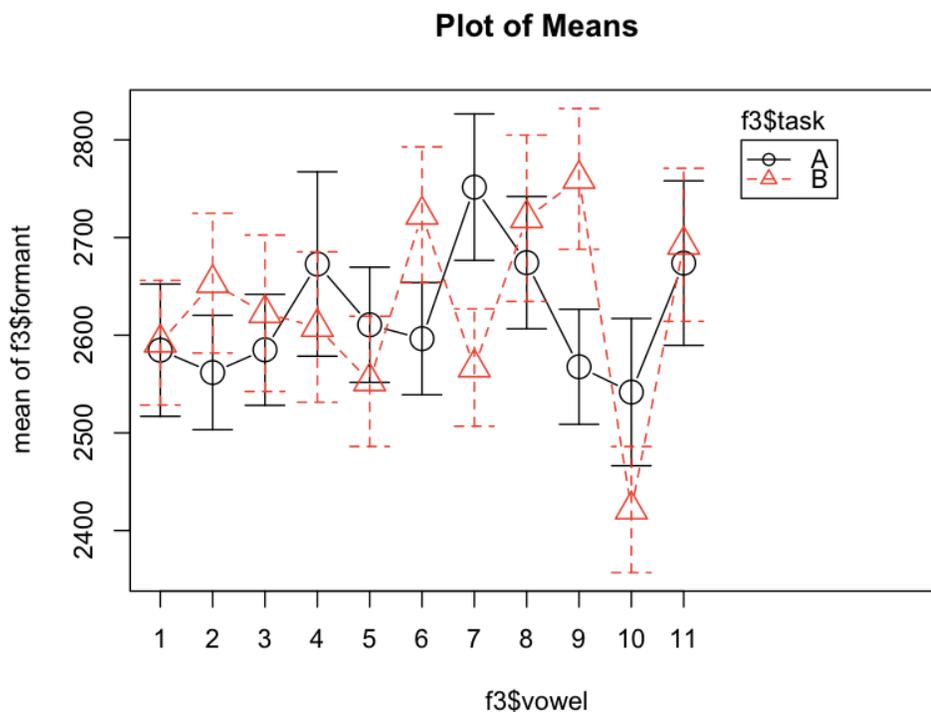


Figure 4.28 Vowel contexts and task formalities (mean F3)

4.4 Research Question 4: Elicitation tasks

4a. Does the formality of elicitation tasks (i.e., word-reading versus mini-dialogue) have an impact on the acoustic features of /l/ variations with regards to F1?

Since the normal distribution test was done previously and the results were shown in Section 4.3, the researcher will present the results of the four-way ANOVA tests only in this section. As is shown in Table 4.11, the p-value of the first response factor “Task” is greater than 0.05, which indicates that there is no significant difference in F1 between the two types of tasks.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Task	1	0.0701	=0.7913
Group: Task	1	5.9303	<0.05

Types: Task	1	0.6006	=0.4390
Task: Vowel	10	0.4744	=0.9058
Group: Types: Task	1	5.0607	<0.05
Group: Task: Vowel	10	1.9365	<0.05
Types: Task: Vowel	10	0.8605	=0.5709
Group: Types: Task: Vowel	10	0.2950	=0.9819

Table 4.11 Four-way ANOVA test results for elicitation tasks analysis (F1)

The researcher then plotted the mean F1 value for the word list task (Task A in Figure 4.29) and the mini dialogue task (Task B in Figure 4.29). The Figure below confirms the results from Table 9 in that the mean F1 value for Task A and Task B are almost the same.

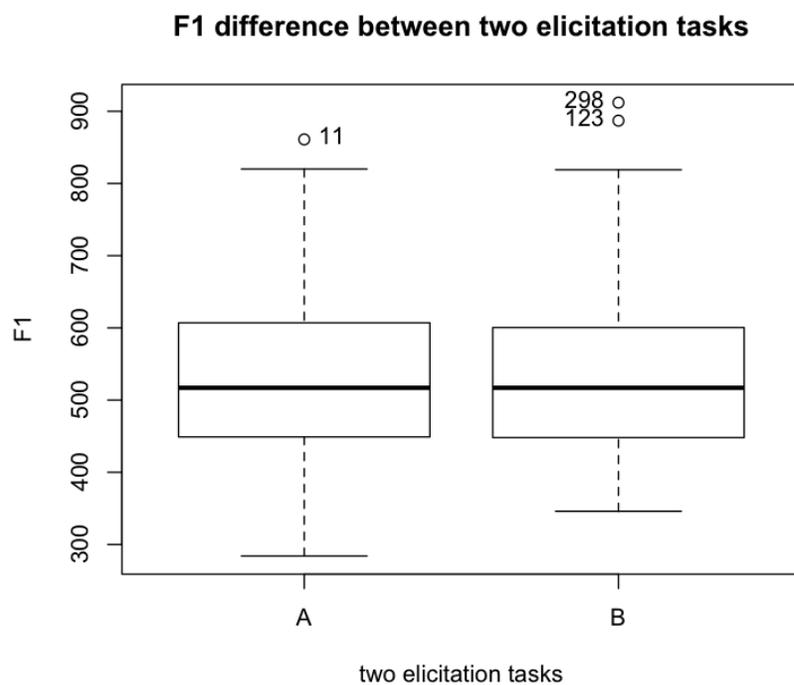


Figure 4.29 Mean F1 comparisons between the two elicitation tasks (mean F1)

4b. Does the formality of elicitation tasks (i.e., word-reading versus mini-dialogue) have an impact on the acoustic features of /l/ variations with regards to F2?

As is shown in Table 4.12, the p-value of the first response factor “Task” is smaller than 0.05, which indicates that there is a significant difference in F2 between the two types of tasks.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Task	1	4.6266	<0.05
Group: Task	1	0.0295	=0.8636
Types: Task	1	11.4260	<0.01
Task: Vowel	10	0.2360	=0.9924
Group: Types: Task	1	0.1229	=0.7261
Group: Task: Vowel	10	0.8747	=0.5574
Types: Task: Vowel	10	0.3154	=0.9767
Group: Types: Task: Vowel	10	0.6279	=0.7895

Table 4.12 Four-way ANOVA test results for elicitation tasks analysis (F2)

The researcher then plotted the mean F2 value for the word list task (Task A in Figure 4.30) and the mini dialogue task (Task B in Figure 4.30). The figure below shows that F2 is higher in the word list task than the mini dialogue task.

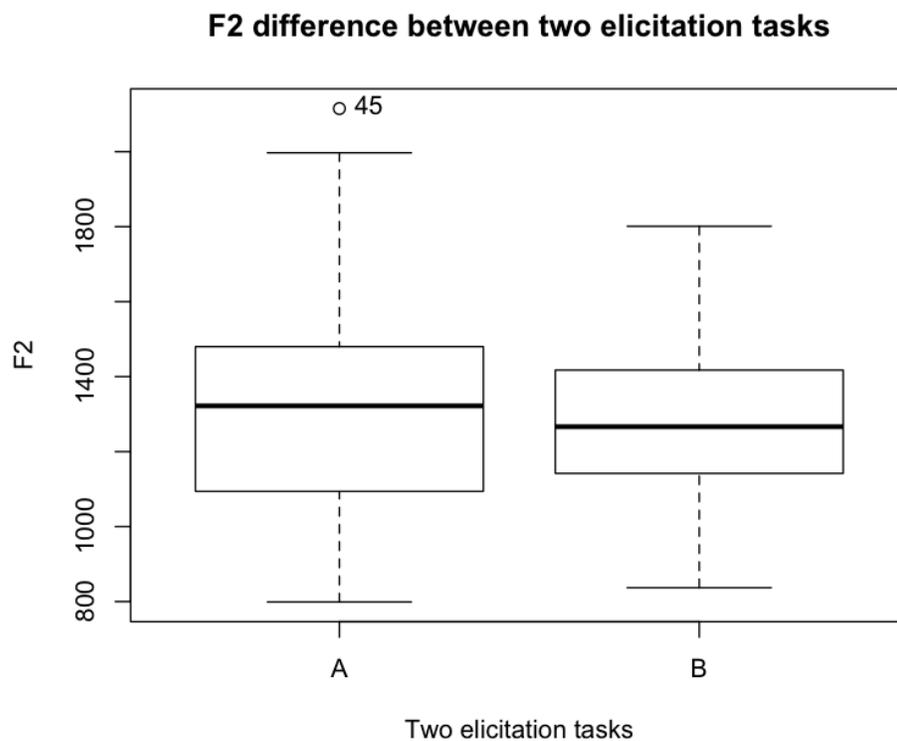


Figure 4.30 Mean F2 comparisons between the two elicitation tasks (mean F2)

4c. Does the formality of elicitation tasks (i.e., word-reading versus mini-dialogue) have an impact on the acoustic features of /l/ variations with regards to F3?

As is shown in Table 4.13, the p-value of the first response factor “Task” is greater than 0.05, which indicates that there is no significant difference in F3 between the two types of tasks.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Task	1	0.0715	=0.7894
Group: Task	1	6.0873	<0.05
Types: Task	1	0.0404	=0.8407
Task: Vowel	10	1.1115	=0.3535

Group: Types: Task	1	0.1922	=0.6614
Group: Task: Vowel	10	0.5618	=0.8443
Types: Task: Vowel	10	0.3093	=0.9784
Group: Types: Task: Vowel	10	0.3430	=0.9684

Table 4.13 Four-way ANOVA test results for elicitation tasks analysis (F3)

The mean F2 values for the word list task (Task A in Figure 4.31) and the mini dialogue task (Task B in Figure 4.31) are shown in the Figure below. The Figure confirms the results from Table 11 in that the mean F3 values for Task A and Task B are almost the same.

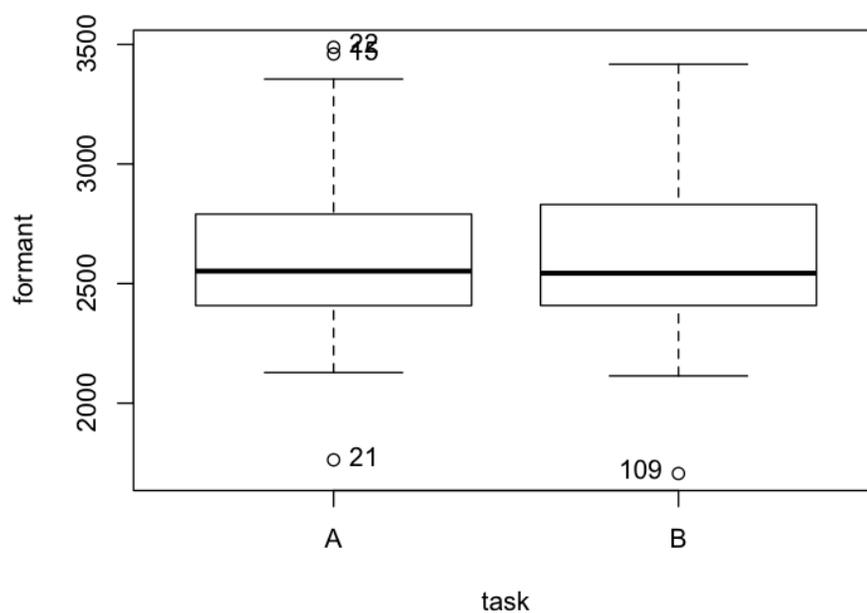


Figure 4.31 Mean F3 comparisons between the two elicitation tasks (mean F3)

4.5 Research Question 5: Comparison between English and Chinese speakers

5a. *What are the similarities and differences between the /l/ production of native and Mandarin Chinese speakers with regards to F1?*

The mean F1 values and the standard deviations of the onset and coda /l/s in two different elicitation tasks are provided below.

Task/Type	Group	Mean (Hz)	Sd (Hz)
Word list onset	Mandarin	471.75	90.64
	English	465.04	79.28
Word list coda	Mandarin	666.59	103.01
	English	552.12	72.74
Mini dialogue onset	Mandarin	464.74	87.67
	English	462.22	59.09
Mini dialogue coda	Mandarin	640.16	105.63
	English	602.30	93.13

Table 4.14 Descriptive statistics for group comparison (F1)

As is shown in Table 4.15, the p-value of the first response factor “Group” is smaller than 0.01, which indicates that there is a very significant difference in F1 between the two groups of speakers (Mandarin Chinese and Canadian English speakers).

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Group	1	20.0910	<0.01
Group: Types	1	15.2666	<0.01

Group: Task	1	5.9303	<0.05
Group: Vowel	10	1.2708	=0.2470
Group: Types: Task	1	5.0607	<0.05
Group: Types: Vowel	10	1.9365	<0.05
Group: Task: Vowel	10	0.6396	=0.7792
Group: Types: Task: Vowel	10	0.2950	=0.9819

Table 4.15 Four-way ANOVA test results for group comparisons (F1)

As is shown in Figure 4.32, for onset /l/ production there is not much difference in F1 values between Chinese and English speakers. Chinese speakers have higher F1 values in their coda /l/ production compared with their English counterparts.

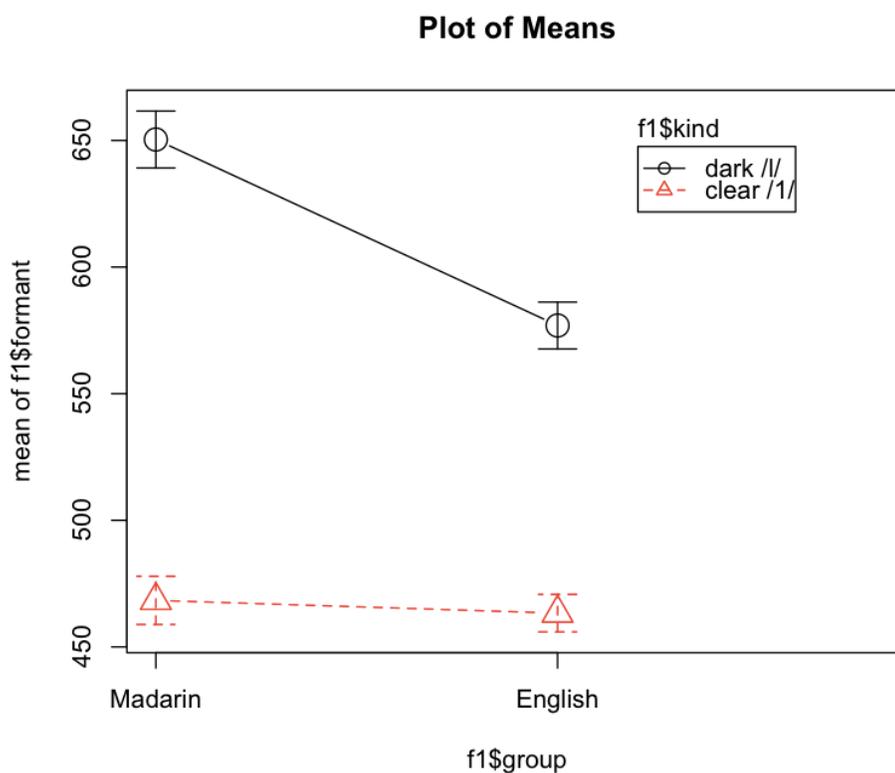


Figure 4.32 Groups of speakers and /l/ variations (mean F1)

Figure 4.33 demonstrates that in both word list and mini dialogue tasks the F1 value of the production of Mandarin Chinese speakers is higher than that of the English speakers. For Mandarin Chinese speakers, they produce the /l/ variations with slightly higher F1 in the word list task. Contrary to the Chinese speakers, the Canadian English speakers produce words with higher F1 in the mini dialogue task than in the word list task.

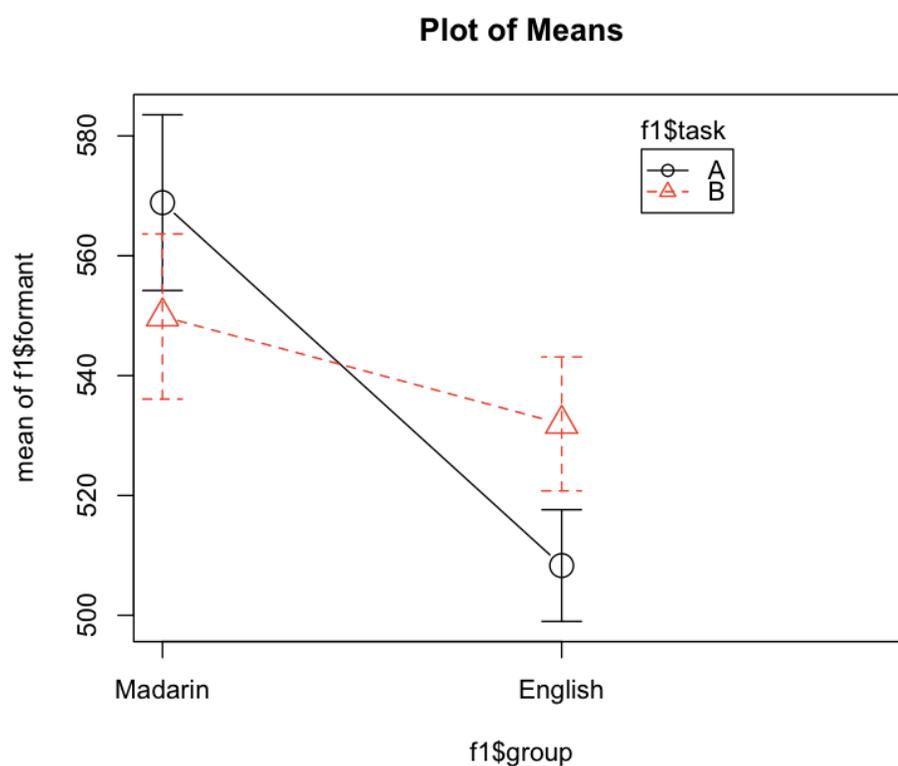


Figure 4.33 Groups of speakers and task formalities (mean F1)

5b. What are the similarities and differences between the /l/ production of native and Mandarin Chinese speakers with regards to F2?

The mean F2 values and the standard deviations of the onset and coda /l/s in two different elicitation tasks are provided in Figure 4.16.

Task/Type	Group	Mean (Hz)	Sd (Hz)
Word list onset	Mandarin	1529.40	224.15
	English	1377.93	214.04
Word list coda	Mandarin	1127.36	158.05
	English	1243.25	196.25
Mini dialogue onset	Mandarin	1416.16	179.58
	English	1271.69	154.20
Mini dialogue coda	Mandarin	1162.30	169.55
	English	1257.27	173.71

Table 4.16 Descriptive statistics for group comparison (F2)

Table 4.17 demonstrates that the p-value of the first response factor “Group” is greater than 0.05, which indicates that there is no significant difference in F2 between the two groups of speakers (Mandarin Chinese and Canadian English speakers).

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Group	1	1.1573	=0.2830
Group: Types	1	40.7353	<0.01
Group: Task	1	0.0295	=0.8636
Group: Vowel	10	1.7181	=0.0767

Group: Types: Task	1	0.1229	=0.7261
Group: Types: Vowel	10	0.8747	=0.5574
Group: Task: Vowel	10	0.5425	=0.8591
Group: Types: Task: Vowel	10	0.6279	=0.7895

Table 4.17 Four-way ANOVA test results for group comparisons (F2)

In their onset and coda /l/ production, Mandarin Chinese speakers demonstrate a wider range of F2 values than the English speakers (shown in Figure 4.34). Mandarin Chinese speakers' coda /l/ production has a lower mean F2 value than the English speakers, however, their onset /l/ production has a higher mean F2 value than the other group.

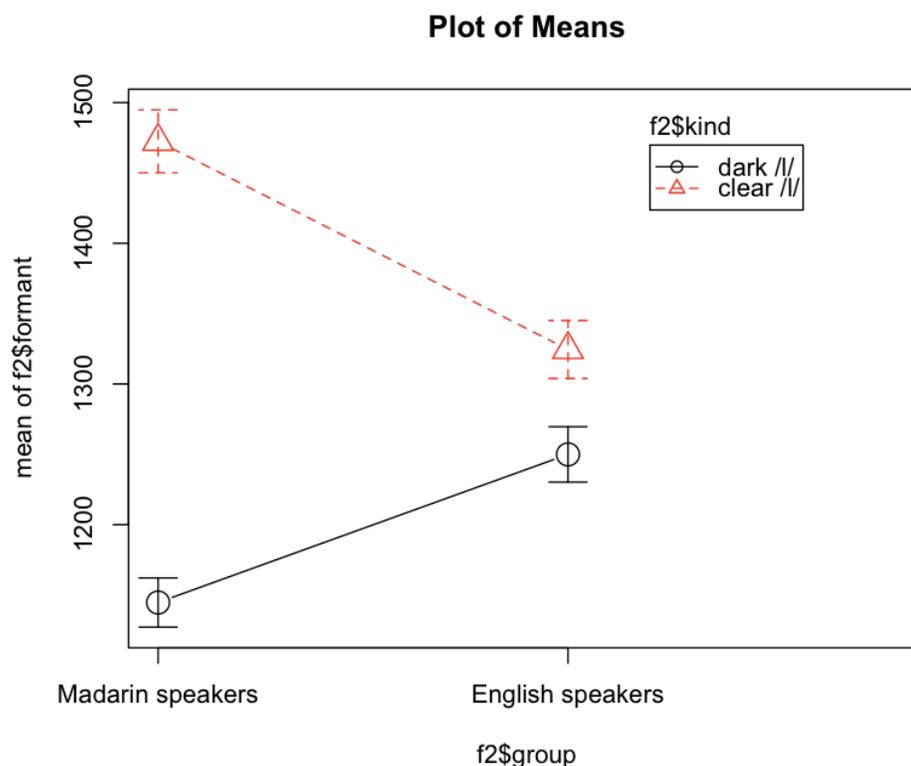


Figure 4.34 Groups of speakers and /l/ variations (mean F2)

For both Chinese and English speakers, their /l/ productions have a higher mean F2 value in the word list task than the mini dialogue task (shown below). There is little difference in mean F2 between the groups of speakers in any given task.

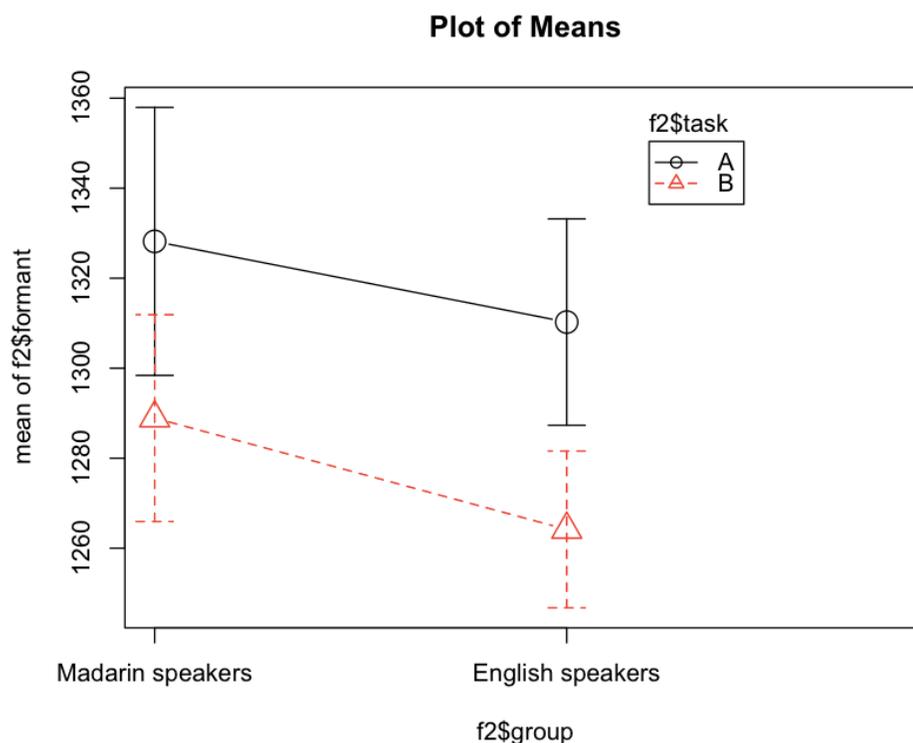


Figure 4.35 Groups of speakers and task formalities (mean F2)

5c. What are the similarities and differences between the /l/ production of native speaker and Mandarin Chinese speakers with regards to F3?

The mean F3 values and the standard deviations of the onset and coda /l/s in two different elicitation tasks are provided in Figure 4.18.

Task/Type	Group	Mean (Hz)	Sd (Hz)
Word list onset	Mandarin	2691.86	262.44
	English	2498.17	191.11

Word list coda	Mandarin	2653.69	297.38
	English	2637.81	312.30
Mini dialogue onset	Mandarin	2632.24	253.67
	English	2563.34	221.38
Mini dialogue coda	Mandarin	2577.77	292.77
	English	2743.74	365.54

Table 4.18 Descriptive statistics for group comparison (F3)

As is shown in Table 4.19, the p-value of the first response factor “Group” is greater than 0.05, which indicates that there is no significant difference in F3 between Mandarin Chinese and Canadian English speakers.

Response	<i>df</i>	<i>F value</i>	<i>p</i>
Group	1	0.7593	=0.3843
Group: Types	1	10.6733	<0.01
Group: Task	1	6.0873	<0.05
Group: Vowel	10	0.2902	=0.9830
Group: Types: Task	1	0.1922	=0.6614
Group: Types: Vowel	10	0.2848	=0.9842
Group: Task: Vowel	10	0.5618	=0.8443
Group: Types: Task: Vowel	10	0.3430	=0.9684

Table 4.19 Four-way ANOVA test results for group comparisons (F3)

In their onset and coda /l/ production, Canadian English speakers demonstrate a greater range of F3 values than the Chinese speakers (shown in Figure 4.36). The English speakers' onset /l/ production has a lower mean F3 value than the Chinese speakers, however, their coda /l/ production has a higher mean F3 value than the Chinese group.

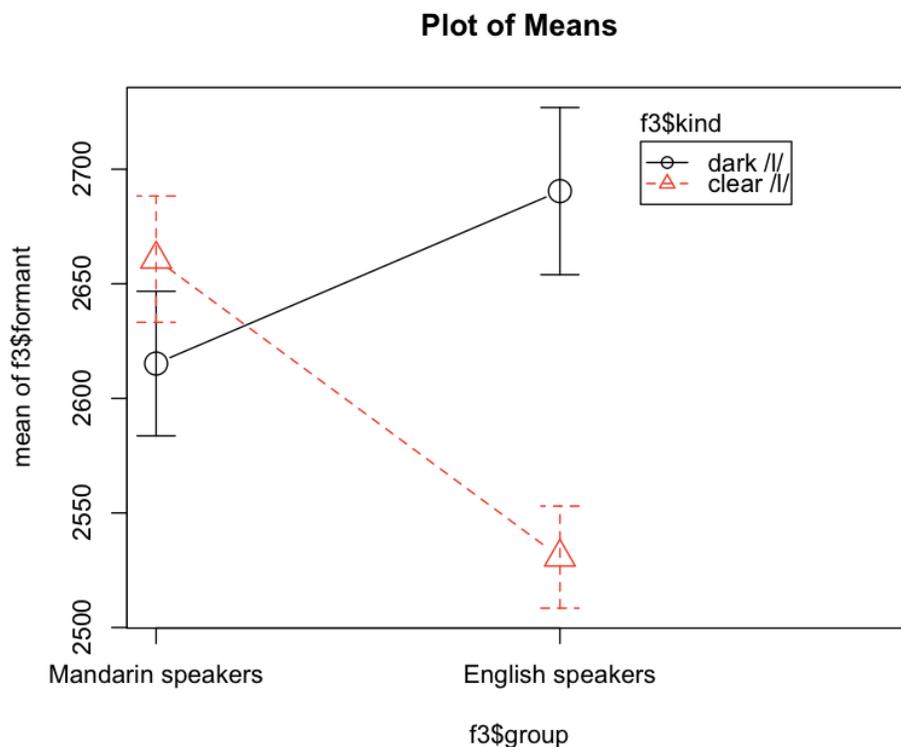


Figure 4.36 Groups of speakers and /l/ variations (mean F3)

As is demonstrated in Figure 4.37, the production of Mandarin speakers has a higher mean F3 value in the word list task than the English speakers and a lower mean F3 in the mini dialogue task than the English group.

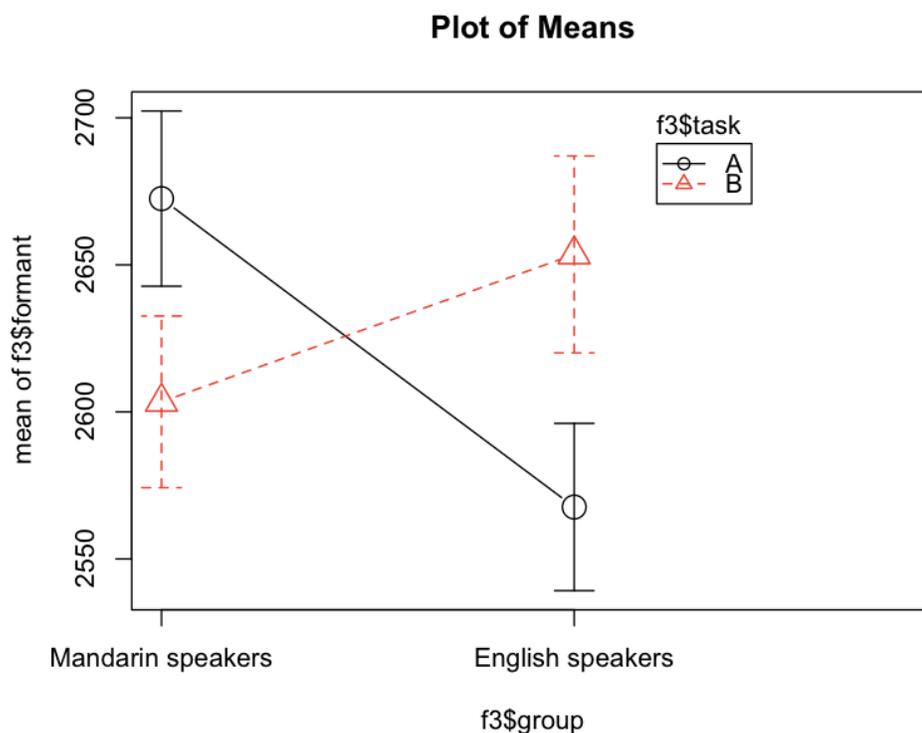


Figure 4.37 Groups of speakers and task formalities (mean F3)

5d. Group comparisons by task formality and the type of /l/ variations

After the four-way ANOVA tests, the researcher did twelve one-way ANOVAs to compare the similarities and differences between Canadian English speakers and Mandarin Chinese speakers under each of the four conditions: onset /l/ in word list task, coda /l/ in word list task, onset /l/ in mini dialogue task, and coda /l/ in mini dialogue task.

Formant	<i>df</i>	<i>F value</i>	<i>p</i>
F1	1	36.22	<0.01
F2	1	9.254	<0.01
F3	1	0.061	=0.806

Table 4.20 Group comparison results for onset /l/ in word list task

As is indicated in Table 4.20, there is significant difference ($p < 0.01$) between the two groups of speakers in F1 and F2 measurements of their onset /l/ production in the word list task. No significant difference ($p > 0.05$) is detected in the F3 measurements.

Formant	<i>df</i>	<i>F value</i>	<i>p</i>
F1	1	0.135	=0.715
F2	1	10.52	<0.01
F3	1	15.67	<0.01

Table 4.21 Group comparison results for coda /l/ in word list task

Table 4.21 demonstrates that there is significant difference ($p < 0.01$) between the two groups of speakers in F2 and F3 measurements of their coda /l/ production in the word list task. No significant difference ($p > 0.05$) is detected in the F1 measurements.

Formant	<i>df</i>	<i>F value</i>	<i>p</i>
F1	1	2.317	=0.132
F2	1	6.728	<0.05
F3	1	5.564	<0.05

Table 4.22 Group comparison results for onset /l/ in mini dialogue task

Table 4.22 reveals that there is significant difference ($p < 0.05$) between the two groups of speakers in F2 and F3 measurements of their onset /l/ production in the mini dialogue task. No significant difference ($p > 0.05$) is detected in the F1 measurements.

Formant	<i>df</i>	<i>F value</i>	<i>p</i>
F1	1	0.045	=0.833
F2	1	6.728	<0.05
F3	1	1.696	=0.196

Table 4.23 Group comparison results for coda /l/ in mini dialogue task

As is indicated in Table 4.23, there is significant difference ($p < 0.05$) between the two groups of speakers in F2 measurements of their coda /l/ production in the mini dialogue task. No significant difference ($p > 0.05$) is detected in both F1 and F3 measurements.

To conclude, this chapter presents the audio and ultrasound video analysis results obtained to answer the five research questions of this paper. The first and second sections of this chapter addressed the question of the acoustic and articulatory features of the onset and coda /l/s that were produced by Mandarin Chinese and Canadian English speakers. The third section answered the question of the impact of vowel contexts on the acoustic features of the /l/ variations. Then the fourth section discussed the influence of the elicitation tasks on the production of the /l/ variations. The last part of the chapter presented the test results for research question five on the similarities and differences between the production of the Mandarin Chinese and the Canadian English speakers.

Chapter 5

Discussion and Conclusion

5.1 Key Findings

5.1.1 Acoustic and articulatory features of onset and coda /l/s as produced by Canadian English speakers

The present study investigated the English onset and coda /l/s produced by four Canadian English speakers and four Mandarin Chinese speakers in two elicitation tasks, namely, word list task and mini dialogue task.

For onset /l/s that were produced by English speakers in the word list task, the mean formant values are: F1 465.04 ± 79.28 Hz, F2 1377.93 ± 214.04 Hz, F3 2498.17 ± 191.11 Hz. For coda /l/s, the mean formant values are: F1 552.12 ± 72.74 Hz, F2 1243.25 ± 196.25 Hz, F3 2637.81 ± 312.20 Hz. The range of F2-F1 means is 619.57 Hz to 1206.21 Hz for onset /l/s and 422.14 Hz to 960.12 Hz for coda /l/s. For comparison, Sproat and Fujimura (1993) reported a range of 904.23 Hz to 1315 Hz for word initial /l/s and 515.34 Hz to 908.96 Hz for word final /l/s. The Canadian English speakers produced both onset and coda /l/s with greater F2-F1 distances than the word initial and final /l/s in Sproat and Fujimura's study.

Espy-Wilson (1992) provided the average formant frequencies of prevocalic and postvocalic /l/s in her study. For prevocalic /l/, the formant frequencies are: F1 399 Hz, F2 1074 Hz, F3 2533 Hz, and F4 3767 Hz. The mean F1 and F2 values are lower in Espy-Wilson's study than in the present research.

The ultrasound data from the word list task produced by the Canadian English speakers confirmed Sproat and Fujimura's finding that lowering of the tongue dorsum was the main articulatory feature of word coda /l/s. Only English Participant 1 demonstrated noticeable tongue retraction during his or her coda /l/ production. The other three participants either lowered the tongue dorsum (participant 2 and 3) or held the same tongue position as onset /l/s.

Sproat and Fujimura (1993) pointed out that velarization was not the articulatory feature of coda /l/ since in their studies the tongue dorsum showed no signs of rising towards the velum. The finding was also partly confirmed by the present study since only one out of four participants demonstrated noticeable tongue dorsum rising towards the velum region.

For onset /l/s that were produced by English speakers in the mini dialogue task, the mean formant values are: F1 462.22 ± 59.09 Hz, F2 1271.69 ± 154.20 Hz, F3 2563.34 ± 221.38 Hz. For coda /l/s, the mean formant values are: F1 602.30 ± 93.13 Hz, F2 1257.27 ± 173.71 Hz, F3 2743.74 ± 365.54 Hz. The range of F2-F1 means is 596.18 Hz to 1022.76 Hz for onset /l/s and 388.13 Hz 921.81 Hz for coda /l/s. Compared with Sproat and Fujimura's (1993) report, the present data showed greater F2-F1 distances for both onset and coda /l/s, which is consistent with the finding from the word list task. As well, the mean F1 and F2 values of both onset and coda /l/s were higher than the data reported by Espy-Wilson (1992).

According to the ultrasound analysis results, the four English participants demonstrated a greater degree of tongue retraction and the lowering of the tongue dorsum in the mini dialogue task than in the word list task. All four English participants showed significant

tongue retraction. Even though the researcher did not conduct a statistical analysis for the ultrasound data, the differences in tongue dorsum retraction between the two elicitation tasks were still fairly noticeable by comparing the superimposed images.

5.1.2 Acoustic and articulatory features of onset and coda /l/s as produced by Mandarin Chinese speakers

With regards to the onset /l/s that were produced by Mandarin Chinese speakers in the word list task, the mean formant values are: F1 471 ± 90.64 Hz, F2 1529.40 ± 224.15 Hz, F3 2691.86 ± 262.44 Hz. For coda /l/s, the mean formant values are: F1 666.59 ± 103.01 Hz, F2 1127.36 ± 158.05 Hz, F3 2653.69 ± 297.38 Hz. The range of F2-F1 means is 743.61 Hz to 1373.19 Hz for onset /l/s and 199.71 Hz to 721.83 Hz for coda /l/s. The Chinese speakers' onset and coda /l/production had wider F2-F1 ranges than both the Canadian English speakers and the English speaking participants from Sproat and Fujimura's (1993) study. The mean F1 and F2 of the /l/ production were higher in the present study than the results reported by Espy-Wilson (1992).

All four Mandarin Chinese speakers demonstrated greater level of tongue retraction than the English speakers when they were producing the same stimuli in the word list task. This articulatory characteristic, namely, velarization, was acknowledged by a number of scholars (Browman & Goldstein, 1995; Clark & Yallop, 1995; Narayanan & Alwan, 1997; Recasens, 2004; Wrench, 2003; Yang, 2008) as the most distinctive feature of dark /l/. The fact that Mandarin Chinese speakers showed a greater degree of velarization than the Canadian English speakers may be explained by over correction of second language learners. Lowering the tongue dorsum was also a noticeable feature of the coda /l/ production by Chinese speakers.

For onset /l/s that were produced by Mandarin Chinese speakers in the mini dialogue task, the mean formant values are: F1 464.74 ± 87.67 Hz, F2 1416.16 ± 179.58 Hz, F3 2632.24 ± 253.67 Hz. For coda /l/s, the mean formant values are: F1 640.16 ± 105.63 Hz, F2 1162.30 ± 169.55 Hz, F3 2577.77 ± 292.77 Hz. The range of F2-F1 means is 684.17 Hz to 1218.67 Hz for onset /l/s and 246.96 Hz to 797.32 Hz for coda /l/s. The Chinese speakers' onset and coda /l/production had wider F2-F1 ranges than both the Canadian English speakers and the participants from Sproat and Fujimura's (1993) study. The mean F1 and F2 of the /l/ production were also higher in the present study than the results reported by Espy-Wilson (1992).

The ultrasound data collected in the mini dialogue task was consistent with the results from the word list task. Tongue retraction and lowering were observable from the superimposed ultrasound images. For all four Chinese participants, the tongue retraction was less obvious in the mini dialogue task than in the word list task. Faster speech rate and less thinking time in the mini dialogue task may have resulted in this reduced degree of tongue retraction in the mini dialogue task for Mandarin Chinese speakers.

For the four English speakers, their tongue contours differed considerably, considering they were all native English speakers. Part of the reason may be that two of the participants were male while the other two were female. The physiological difference in the size and the shape of the vocal tract between men and women may explain why the tongue contours did not demonstrate a consistent movement tendency. Another possible reason may be that the speech rate was not a controlled factor in this experiment. During the data collection phase, the researcher noticed that the two male speakers spoke at a slower rate than the two female speakers. The male speakers may have wanted to present

clearer ultrasound images so that they slowed down their speech rate even though it was not asked of them.

5.1.3 The influence of vowel context on onset and coda /l/ production

According to the ANOVA results, vowel contexts had limited impact on the quality of /l/ production. Figure 4.18 shows that except for the vowels /a/ and /æ/, the F1 values remained almost constant in all the other vowel contexts. With regards to the variations in F2 values, both onset and coda /l/s in the /i/ and /a/ contexts had more distinctive formant frequencies than the other contexts. Figure 4.26 demonstrated that both onset and coda /l/s had the lowest F3 values in the /ə/ vowel context. Overall, for all three formant frequencies measured in the present study, the quality of both onset and coda /l/s varied very little except for certain particular vowel contexts.

5.1.4 The influence of task formality on onset and coda /l/ production

As was suggested by the ANOVA test results, task formality played a small role in the quality of the onset and coda /l/ production. There was no significant difference between the /l/ production in the word list task and the mini dialogue task in F1 and F3 values. With regards to F2, there was a significant difference ($p < 0.05$) between the two elicitation tasks.

According to Weinberger (1987), formality and ESL speakers' proficiency levels are the reasons for the different qualities in speech production. Word-list reading is considered to be the most formal way of testing speakers' production while spontaneous speech in a relaxed environment is considered to be the least formal way of collecting

speech data. In the present study both word list task and mini dialogue task were performed to see if task formality plays a role in the quality of /l/ production.

Different from Weinberger's (1987) prediction, in the present study there was very little difference between the two elicitation tasks. This may partly be due to the fact that mini dialogue is not a fully spontaneous speech and that the experiment setting was in a phonetics lab, which could raise the level of nervousness in the participants.

5.1.5 The similarities and differences between Canadian English speakers and Mandarin Chinese speakers

As was demonstrated in Figure 4.32, for onset /l/ production Canadian English and Mandarin Chinese speakers had almost the same F1 values, which indicates that during onset /l/ production they held very similar tongue height positions. Mandarin Chinese speakers had lower tongue position when they were producing English coda /l/s (mean F1 equals 650 Hz) compared with the English speakers (mean F1 is around 580 Hz). The difference was confirmed by the ANOVA tests ($p < 0.01$).

According to He and Lin (2004, 2005), Mandarin Chinese speakers tended to replace English coda /l/ with some kind of back vowel or their diphthongized or glide variations. This finding was confirmed by the present study in that in Figure 4.34, Mandarin Chinese speakers had lower F2 during their coda /l/ production, which indicates that their tongue is more retracted than their English counterparts. The difference was significant as was indicated by the ANOVA tests. For word coda /l/ in word list task, the p-value for the difference between Canadian English speakers and Mandarin Chinese speakers in F2 was smaller than 0.01. In the mini dialogue task, the p-value for the group difference in F2 was smaller than 0.05.

For word onset /l/ production, Mandarin Chinese speakers (mean F2 at around 1480 Hz) had more front tongue positions than the English participants (mean F2 at around 1340 Hz). The difference in tongue heights was also significant in both the word list task ($p < 0.01$) and the mini dialogue task ($p < 0.05$).

There was little difference between the groups of speakers with regards to F3 ($p > 0.05$). For the word onset /l/, the p-value is greater than 0.05 in the word list task and smaller than 0.05 in the mini dialogue task. For the word coda /l/, the p-value is greater than 0.05 in the mini dialogue task and smaller than 0.05 in the word list task.

5.2 Summary and Conclusion

The study investigated the acoustic qualities and articulatory features of the English onset and coda /l/s produced by both Canadian English and Mandarin Chinese speakers. Eleven vowel contexts and two elicitation tasks were included to test the quality of /l/ production under different conditions. Acoustic analysis was done by running four-way and repeated one-way ANOVAs. The statistical measurements such as the mean and standard deviations of each formant were obtained. The ultrasound data were analysed by using EdgeTrak and Microsoft Excel spreadsheet. The acoustic and articulatory results have provided answers to the five research questions of this paper:

1a. What are the acoustic features of the /l/s produced by Canadian English speakers?

For onset /l/s that were produced by English speakers in word list task, the mean formant values with standard deviations are: F1 465.04 ± 79.28 Hz, F2 1377.93 ± 214.04 Hz, F3 2498.17 ± 191.11 Hz. For coda /l/s produced by English speakers in word list task,

the mean formant values with standard deviations are: F1 552.12 ± 72.74 Hz, F2 1243.25 ± 196.25 Hz, F3 2637.81 ± 312.20 Hz. The mean F1, F2 and F3 values of both onset and coda /l/s produced by the Canadian English speakers in two elicitation tasks were provided and compared with the results from Sproat and Fujimura (1993) and Espy-Wilsons' (1992) studies. In both word list and mini dialogue tasks, the English speakers' mean F2-F1 ranges were greater than that from Sproat and Fujimura's study. The mean F1 and F2 values were higher than the observations of Espy-Wilson (1992). This may indicate that dialect variation is a factor in the quality of /l/ production since all the English speakers from the present study were born and raised in Canada, whereas in the other two studies the participants all spoke American English.

1b. What are the articulatory features of the /l/s produced by Canadian English speakers?

In the word list task, only one out of the four Canadian English speakers demonstrated noticeable tongue dorsum rising towards the velum region. However, in the mini dialogue task, the English participants showed a greater level of tongue rising towards the velum. The ultrasound data collected in the word list task confirmed Sproat and Fujimura's (1993) finding that velarization was not the most prominent articulatory feature of coda /l/s. Even though the ANOVA tests provided in the task formality section of this paper did not detect any significant difference between word list and mini dialogue tasks, the qualitative results may still offer a perspective towards the debate about velarization in word coda /l/.

2a. What are the acoustic features of the /l/s produced by Mandarin Chinese speakers?

For onset /l/s that were produced by Mandarin Chinese speakers in the word list task, the mean formant values and the standard deviations are: F1 471 ± 90.64 Hz, F2 1529.40 ± 224.15 Hz, F3 2691.86 ± 262.44 Hz. For coda /l/s produced by Mandarin Chinese speakers in word list task, the mean formant values and the standard deviations are: F1 666.59 ± 103.01 Hz, F2 1127.36 ± 158.05 Hz, F3 2653.69 ± 297.38 Hz.

The mean F1, F2 and F3 values of both onset and coda /l/s produced by the Mandarin Chinese speakers in two elicitation tasks were provided and compared with the English speakers from this study, the results from Sproat and Fujimura (1993) and Espy-Wilson's (1992) studies. Mandarin Chinese speakers' mean F2-F1 ranges were smaller than that of the Canadian English speakers in this study but greater than the observed results from Sproat and Fujimura's study. The mean F1 and F2 values of the /l/ production by the Mandarin Chinese group were higher than the observations of Espy-Wilson (1992).

2b. What are the articulatory features of the /l/s produced by Mandarin Chinese speakers?

The ultrasound data collected in the two tasks produced by Mandarin Chinese speakers showed both tongue retraction and the lowering of the tongue dorsum. Since ultrasound cannot show the velum region of the vocal tract, it is difficult to draw the exact line between tongue dorsum retraction and velarization. Judging from the superimposed ultrasound images, Mandarin Chinese speakers did demonstrate a greater level of tongue

retraction, which confirmed He and Lin's (2004, 2005) finding that Mandarin Chinese speakers tended to produce coda /l/s as a back vowel or their diphthongized or glide variations.

3. *Do vowel contexts have an impact on the acoustic features of the /l/ variations?*

As was indicated by the ANOVA test results, vowel contexts had limited impact on the acoustic qualities of the onset and coda /l/s produced by both group of speakers.

However, under certain vowel contexts, more specifically, /ɑ/, /æ/, and /ə/, the formant frequencies of both onset and coda /l/s varied a lot compared with other vowel contexts.

4. *Does the formality of elicitation tasks (i.e., word-reading versus mini-dialogue) have an impact on the acoustic features of /l/ variation*

Task formality played a small role in the acoustic quality of the onset and coda /l/ production. There was no significant difference between the /l/ production in the word list task and the mini dialogue task in F1 and F3 values. Even though there was a significant difference ($p < 0.05$) between the two elicitation tasks in F2 values, the overall difference (as indicated by Figure 4.29, 4.30, and 4.31) was very small.

5. *What are the similarities and differences between the /l/ production of the two groups of speakers?*

For word onset /l/ production, Mandarin Chinese speakers had more front tongue positions (higher F2) than the English speakers. The degree of frontness was affected by

the formality of the task. In word list task, the Chinese participants' tongue blade was more front than in the mini dialogue task.

For word coda /l/s, Mandarin Chinese speakers had lower (high F1) and more retracted (low F2) tongue positions than their English counterparts. This finding is consistent with the studies done by He and Lin (2004, 2005) in that it confirmed Mandarin Chinese speakers' tendency to produce coda /l/s with vocalic gestures, in other words, more like a back vowel. To examine ESL speakers' dark /l/ productions He & Lin (2004) used native judgment whereas the present paper used acoustics and ultrasound instruments. In the future studies, it would benefit if both native judgement and instrumental measurements were adopted in the same study.

The findings of this study were based on an analysis of four Canadian and four Chinese participants. To confirm the findings of this study, it would be necessary to extend the approach employed in this study to more English and Chinese participants. Statistical comparisons for ultrasound data would help in providing more accurate quantitative descriptions of the articulatory features of the /l/ production. A closer look at the data indicates that the formant values of the dark /l/s produced by native Canadian English speakers are most resemble that of the back vowel /ʊ/. For Mandarin Chinese speakers, their dark /l/ productions sound more like a mid-back vowel /o/. In the future acoustic analysis part, it may be helpful to look into the formant values of the adjacent vowels as well as the consonant /l/s.

Bibliography

- Adler-Bock, M. (2007). The use of ultrasound in remediation of North American English /r/ in 2 adolescents. *American Journal of Speech-Language Pathology*, 16 (2), 128-139.
- Adams, A., & Cox, A. L. (2008). Questionnaires, in-depth interviews and focus groups. In: Cairns, Paul and Cox, Anna L (Eds). *Research Methods for Human Computer Interaction* (pp. 17–34). Cambridge, UK: Cambridge University Press.
- Anderson, J. (1987). The markedness differential hypothesis and syllable structure difficulty. In G. Ioup and S. H. Weinberger (Eds.). *Interlanguage phonology: The acquisition of a second language sound system* (pp. 279-291). Cambridge: Newbury House.
- Ball, M. J., Rahilly, J., & Pickett, J. M. (2000). Phonetics—the science of speech. *The Journal of the Acoustical Society of America*, 108, 2695.
- Benson, B. (1988). Universal preference for the open syllable as an independent process in interlanguage Phonology. *Language Learning*, 38(2), 221-235.
- Brown, J. D., & Rodgers, T. S. (2002). *Doing second language research: An introduction to the theory and practice of second language research for graduate/master's students in TESOL and applied linguistics, and others*. New York: Oxford University Press.
- Brown, K. (2006). Glossary of language and linguistics. *Encyclopaedia of language and linguistics*, 2.

- Burns, A. (2011). Action research in the field of second language teaching and learning. *Handbook of research in second language teaching and learning*, 2, 237-253.
- Browman, C. P., & Goldstein, L. (1995). Gestural syllable position effects in American English. *Producing speech: Contemporary issues*, 19-33.
- Chen, Y. (2011). *An investigation of tongue movement in the production of Mandarin's basic vowels using ultrasound* (Doctoral dissertation, Nankai University).
- Chen, Yu, Hua Lin (2011). Analyzing tongue shape and movement in Vowel Production Using SS ANOVA on Ultrasound Imaging. Proceedings of the 17th International Congress on Phonetic Sciences. pp. 124-127.
- Clark, J., & Yallop, C. (2011). An introduction to phonetics and phonology. Oxford: Blackwell.
- Davidson, L. (2006). Comparing tongue shapes from ultrasound imaging using smoothing spline analysis of variance. *The Journal of the Acoustical Society of America*, 120, 407-415.
- Ding, H., Mixdorff, H., & Jokisch, O. (2010). Pronunciation of German syllable codas of Mandarin Chinese speakers. *Konferenz Elektronische Sprachsignalverarbeitung (ESSV), Berlin*, 281-287.
- Eckman, F. R. (1991). The structural conformity hypothesis and the acquisition of consonant clusters in the interlanguage of ESL learners. *Studies in Second Language Acquisition*, 13(01), 23-41.
- Eckman, F. R., & Iverson, G. K. (1993). Sonority and markedness among onset clusters in the interlanguage of ESL learners. *Second Language Research*, 9(3), 234-252.

- Espy-Wilson, C. Y. (1992). Acoustic measures for linguistic features distinguishing the semivowels/ wjrl/ in American English. *The Journal of the Acoustical Society of America*, 92, 736.
- Field, J., Muir, D., Pilon, R., Sinclair, M., & Dodwell, P. (1980). Infants' orientation to lateral sounds from birth to three months. *Child Development*, 295-298.
- Flege, J. E. (1995). Second language speech learning theory, findings, and problems. In W. Strange (Ed.). *Speech perception and linguistic experience: Issues in cross-language research* (pp. 233-277). Baltimore: York Press.
- Gick, B. (2002). The use of ultrasound for linguistic phonetic fieldwork. *International Phonetic Association*, 32(2), 114-121.
- Gick, B. (2002). The American intrusive l. *American Speech*, 77(2), 167-183.
- Gick, B., Bird, S., & Wilson, I. (2005). Techniques for field application of lingual ultrasound imaging. *Clinical Linguistics & Phonetics*, 19(6/7), 503-514.
- Gick, B., Campbell, F., Oh, S., & Tamburri-Watt, L. (2006). Toward universals in the gestural organization of syllables: A cross-linguistic study of liquids. *Journal of Phonetics*, 34(1), 49-72.
- Giles, S. B., & Moll, K. L. (1975). Cinefluorographic study of selected allophones of English/l. *Phonetica*, 31(3-4), 206-227.
- Greenberg, J.H. (1978). Some generalizations concerning initial and final consonant clusters. In J.H. Greenberg, (ED.), *Universals of Human Language*, II. CA: Stanford University Press.
- Gussenhoven, C., & Jacobs, H. (2011). *Understanding Phonology (Third Edition)*. UK: Hodder Education.

- Hansen, J. G. (2001). Linguistic constraints on the acquisition of English syllable codas by native speakers of Mandarin Chinese. *Applied Linguistics*, 22(3), 338-365.
- Harklau, L. (2011). Approaches and Methods in Recent Qualitative Research. *Handbook of Research in Second Language Teaching and Learning*, 2, 175-89.
- He, Yunjuan, and Hua Lin (2005). Mandarin speakers' production of English /l/ in syllable-final position. Second Language Research Forum 2005, Teachers College, Columbia University, October 2005.
- He, Yunjuan and Hua Lin (2004). Phonetic versus Phonological Influences on Mandarin Listeners Perception of English /l/. Paper presented at the Sixth International Symposium on Applied Linguistics and Language Teaching (Beijing-Shanghai). Beijing, China. August, 2004.
- Hudu, F. (2010). *Dagbani tongue-root harmony: a formal account with ultrasound investigation* (Doctoral dissertation, University of British Columbia).
- James, A. R. (1988). *The acquisition of a second language phonology: A linguistic theory of developing sound structures* (Vol. 9). Germany: Gunter Narr Verlag Tubingen.
- Ladefoged, P., & Maddieson, I. (1996). *The sounds of the world's languages*. Oxford: Blackwell.
- Ladefoged, P., & Johnson, K. (2011). *A course in phonetics (Sixth Edition)*. Boston: Wadsworth.
- Laver, J. (1994). *Principles of phonetics*. New York: Cambridge University Press.
- Leather, J., & James, A. (1991). The acquisition of second language speech. *Studies in Second Language Acquisition*, 13(03), 305-341.

- Li, Ya (2010). *Mandarin Speakers' Production of English and Mandarin Post-Vocalic Nasals: An Acoustic Approach*. (Master's thesis: University of Victoria).
- Lotto, A. J., & Kluender, K. R. (1998). General contrast effects in speech perception: Effect of preceding liquid on stop consonant identification. *Perception and Psychophysics*, 60(4), 602-619.
- Macken, M. A., & Ferguson, C. A. (1981). Phonological universals in language acquisition. *Annals of the New York Academy of Sciences*, 379(1), 110-129.
- Magnuson, T. (2008) *What /r/ sounds like in Kansai Japanese: a phonetic investigation of liquid variation in unscripted discourse*. (Master's thesis, University of Victoria)
- Major, R. C. (1987). A model for interlanguage phonology. In G. Ioup and S. H. Weinberger (Eds.). *Interlanguage phonology: The acquisition of a second language sound system* (pp. 101-124). Cambridge: Newbury House.
- Martins, P., Carbone, I., Pinto, A., Silva, A., & Teixeira, A. (2008). European Portuguese MRI based speech production studies. *Speech Communication*, 50(11), 925-952.
- Mielke, J., Olson, K., Baker, A., & Archangeli, D. (2011). Articulation of the Kagayanen interdental approximant: An ultrasound study. *Journal of Phonetics*, 39(2011), 403 – 412.
- Modha, G., Bernhardt, B., Church, R., & Bacsfalvi, P. (2008). Case study using ultrasound to treat /r/. *International Journal of Language & Communication Disorders*, 43(3), 323-329.
- Moisik, Scott, Hua Lin & John Esling (2013). Larynx height and constriction in Mandarin tone. In PENG, Gang & Feng SHI (eds). *Eastward Flows the Great River: Essays on Contemporary Linguistics and Language Studies*. Festschrift in honor of

- Professor William S-Y. Wang on his 80th Birthday. Hong Kong: City University of Hong Kong Press. pp. 187-205.
- Moisik, Scott, Hua Lin, & John Esling. A study of laryngeal gestures in Mandarin citation tones using simultaneous laryngoscope and laryngeal ultrasound. *Journal of the International Phonetic Association*.
- Narayanan, S. S., Alwan, A. A., & Haker, K. (1997). Toward articulatory-acoustic models for liquid approximants based on MRI and EPG data. Part I. The laterals. *The Journal of the Acoustical Society of America*, 101, 1064.
- Narayanan, S., Byrd, D., & Kaun, A. (1999). Geometry, kinematics, and acoustics of Tamil liquid consonants. *The Journal of the Acoustical Society of America*, 106, 1993.
- Pica, T. (2011). Second language acquisition research applied and applicable orientations to practical questions and concerns. *Handbook of Research in Second Language Teaching and Learning*, 2, 257-269.
- Proctor, M. I. (2009). *Gestural characterization of a phonological class: The liquids* (Doctoral dissertation, Yale University).
- Raphael, L. J. (1972). Preceding vowel duration as a cue to the perception of the voicing characteristic of word-final consonants in American English. *The Journal of the Acoustical Society of America*, 51, 1296-1303.
- Recasens, D. (1996). An articulatory-perceptual account of vocalization and elision of dark/l/ in the Romance languages. *Language and Speech*, 39(1), 63-89.
- Recasens, D. (2004). The effect of syllable position on consonant reduction (evidence from Catalan consonant clusters). *Journal of Phonetics*, 32(3), 435-453.

- Recasens, D. (2012). A cross-language acoustic study of initial and final allophones of /l/. *Speech Communication*, 54(3), 368-383.
- Recasens, D., & Espinosa, A. (2005). Articulatory, positional and coarticulatory characteristics for clear /l/ and dark /l/: evidence from two Catalan dialects. *Journal of the International Phonetic Association*, 35(01), 1-25.
- Recasens, D., & Farnetani, E. (1990). Articulatory and acoustic properties of different allophones of /l/ in American English, Catalan and Italian. Paper presented at International Conference on Spoken Language Processing, Kobe, Japan.
- Sato, C. J. (1984). Phonological processes in second language acquisition: Another look at interlanguage syllable structure. *Language Learning*, 34(4), 43-58.
- Simonet, M. (2010). Dark and clear laterals in Catalan and Spanish: interaction of phonetic categories in early bilinguals. *Journal of Phonetics*, 38(4), 663-678.
- Sproat, R., & Fujimura, O. (1993). Allophonic variation in English /l/ and its implications for phonetic implementation. *Journal of Phonetics*, 21(3), 291-311.
- Stone, M. (1990). A three-dimensional model of tongue movement based on ultrasound and x-ray microbeam data. *Acoustic Society of America*, 87(5), 2207-2217.
- Tarone, E. (2005). Speaking in a second language. *Handbook of research in second language teaching and learning*, 2, 485-502.
- Turton, D. (2011). The darkening of English /l/: a Stochastic Stratal OT analysis. Paper presented at Manchester Phonology Meeting, Manchester, England.
- Weinberger, S. (1987). The influence of linguistic context on syllable simplification. In G. Ioup and S. H. Weinberger (Eds.). *Interlanguage phonology: The acquisition of a second language sound system* (pp. 401-417). Cambridge: Newbury House.

- Wrench, A (2003), An articulatory investigation of word final /l/ and /l/-sandhi in three dialects of English. *Proceedings of the 15th International Congress of Phonetic Sciences*, 2, 1871-1874.
- Yang, B. (2008). An analysis of the English /l/ sound produced by Korean students. *Speech Sciences*, 15(1), 54-62.
- Yuan, J., & Liberman, M. (2009). Investigating /l/ variation in English through forced alignment. *Interspeech*, 10, 2215-2218.
- Yuan, J., & Liberman, M. (2012). /l/ variation in American English: A corpus approach. *Journal of Speech Sciences*, 1(2), 35-46.
- Zhang, Z., & Espy-Wilson, C. Y. (2004). A vocal-tract model of American English /l/. *The Journal of the Acoustical Society of America*, 115, 1274.
- Zhou, X. (2009). *An MRI-Based articulatory and acoustic study of American English liquid sounds /r/ and /l/*. (Doctoral dissertation, University of Maryland).

Appendix 1 Speech Stimuli

1. Word list

Vowel	Single coda /l/ dark	Single onset /l/ clear
/i/	meal	leaves
/ɪ/	bill	lit
/e/	mai	lay
/ɛ/	bell	led
/u/	pool	loop
/ʊ/	pull	look
/o/	bowl	low
/ɑ/	ball	law
/ʌ/	cull	luck
/ə/	curl	lurk
/æ/	pal	lad

2. Mini-dialogues

(Setting: two students in their shared living room)

A: Do you see my **mail**?

B: Yes, it's next to your **bowl**. What is it for?

A: It's my credit card **bill**. By the way, do you know a girl named Mary who used to **curl** her hair with rags?

B: No. But why do you have so many questions today? I'm not Wikipedia that collects information. Try to **cull** the information from other sources.

(Setting: two students are invited for dinner at their friend's house)

A: Did you hear the **bell** ringing?

B: Yes, it is the time to enjoy a delicious **meal**!

A: Right. Allow me to **pull** the chair out for you.

B: You are a real gentleman. Thank you!

(Setting: two friends are playing ball near an outdoor swimming pool)

A: Hey, catch the **ball**!

B: Pardon? Oh, no! The ball dropped into the swimming **pool**!

(Setting: two friends are taking a walk on campus)

A: **Look**. The ground is covered with red **leaves**. It is really beautiful.

B: Yes. I saw a **lad lay** on the grass yesterday.

A: Near the **Law** building? Nice choice.

(Setting: two students are going home on a rainy night)

A: I don't like walking on a **loop** road late at night. One time, I saw a guy **lurked** in the dark behind the trees.

B: Your voice is very **low**. Come on! Don't be afraid.

A: Okay. Oh! Look! The lightening just **lit** up that old post house!

B: All right. Let's run!

(At a celebration party)

A: We are best **pals**!

B: Yes! And you just **led** us win the championship!

A: We have **luck** on our side. Let's celebrate!

Appendix 2 Language Background Survey

1. Your mother tongue (your first language) is:
2. The language you grew up speaking, if different from (1):
3. The hometown you grew up in:
4. How many years did you live in this town?
5. Other places where you have lived for more than 3 months at a time:
6. How long did you live in each of these places?
7. Other than your mother tongue, what language(s) do you know? How well do you know each in terms of speaking, listening, reading and writing? Give a number from 1 to 5 where 1 is for poor and 5 for fluent.

Language 1:

Name: _____ Years of learning: _____

How well the researcher knows the language in terms of speaking _____, listening _____, reading _____ and writing _____

Language 2:

Name: _____ Years of learning: _____

How well the researcher knows the language in terms of speaking _____, listening _____, reading _____ and writing _____

Language 3:

Name: _____ Years of learning: _____

How well the researcher knows the language in terms of speaking _____, listening _____, reading _____ and writing _____

If English is your second language, please answer the following questions:

8. Have you taken any English proficiency test? What test is it if you have?
9. When was the latest one taken?
10. What is your score?

Thank you for taking the time to complete this.



Department of Linguistics, University of Victoria
 P.O. Box 3045 STN CSC, Victoria, BC V8W 3P4
 (250) 721-7424 (phone) (250) 721-7423 (fax)

Participant Consent Form

English /l/s and /r/s as Produced by Native English Speakers and Chinese and Japanese ESL Speakers

You are invited to participate in a study entitled “English /l/s and /r/s as Produced by Native English Speakers and Chinese and Japanese ESL Speakers” that is being conducted by Dr. Hua Lin and her graduate students. We are researchers in the Department of Linguistics at the University of Victoria and you may contact us if you have further questions by phoning Dr. Lin at 250-721-6643 or by sending us email at luahin@uvic.ca; akitsugu@uvic.ca; or nanxingme@gmail.com.

Purpose and Objectives

The purpose of this research is to investigate the differences in tongue configurations and sound qualities of English /l/s and /r/s produced by native English speakers and Chinese and Japanese ESL (English as a Second Language) speakers.

Importance of this Research

Previous Phonetics research has studied the articulatory and acoustic features of these consonants in English and in other languages and have found that English /l/s and /r/s are among the most difficult English consonants for Chinese and Japanese ESL learners. This research can potentially reveal what the fundamental causes of these difficulties are.

What is involved

If you agree to voluntarily participate in this research, your participation will include:

- a) Completing a questionnaire on your language background
- b) Participating in an ultrasound experiment

On the day of the experiment you will first complete a language background survey, which will take approximately 5 minutes. Then you will read a word-list and 5 mini-dialogues during the ultrasound study. The ultrasound recordings will be made using a GE Logiqbook E portable ultrasound machine with an 8C-RS 5-8 MHz transducer at a standard rate of 30 frames per second. The ultrasound transducer will be fixed under your chin to image both the sagittal and coronal view of the tongue movements. There will be practice time for you to get familiar with the machine. The experiment will take approximately 15 minutes to complete.

Ultrasound imaging technique has been used widely in examining articulation process of speech. It can produce real-time tongue movement videos that can be used to examine the articulatory process of word production. The two advantages of ultrasound are its fast imaging speed (60 scans/sec) and its less invasive examining process, compared with MRI or laryngoscope. There is no known hazard of any kind with ultrasound usage.

Meeting with the researchers will take place at the Phonetics Lab at the University of Victoria.

Inconvenience and Risk

Participation in this study may cause some inconvenience to you in the sense that you will need to give up some of your personal time to participate. Apart from this inconvenience there are no known or

anticipated risks to you by participating in this research. As the experiment includes the using of ultrasound, you will be encouraged to take breaks or stop if you are feeling stressed or uncomfortable during any task. Please note that there are no time limits to complete any task. Also, you may decline to answer any questions from any task that may cause you stress or discomfort.

Benefits

The potential benefits to the participants in this research include a better understanding of the acoustic and articulatory properties of participants' native language. Mandarin and Japanese ESL speakers may benefit from this study in that they could learn what causes their difficulties with their English /l/s and /r/s. The potential benefits may also include contribution to the growing body of knowledge on second language articulation and accent.

Voluntary Participation

Your participation in this research must be completely voluntary. If you do decide to participate, please note that you may withdraw at any time without any consequences or any explanation. Should you decide to withdraw at any time during the study, your data will not be used and will be destroyed.

Anonymity

During the data collection process, your identity will be known only to the researcher. When the data is analyzed and results are presented only a code will be used and your identity will not be revealed at any time.

Confidentiality

Your confidentiality and the confidentiality of the data will be protected in the sense that the researcher will not share your data with anyone other than my graduate students. The researcher will not dispose of the data because the researcher may need to confirm my results at a later date. Therefore the researcher will store electronic and digital data on the hard disk of the computer that the researcher has at home. All the data will be stored in password protected computer files.

Future Use of Data PLEASE SELECT STATEMENT:

I consent to the use of my data in future research: _____ (Participant to provide initials)

I do not consent to the use of my data in future research: _____ (Participant to provide initials)

I consent to be contacted in the event my data is requested for future research: _____
(Participant to provide initials)

Destruction of Data/Dissemination of Results

This data may be used for further research by the researcher and the data collected will be kept indefinitely for any further analysis.

It is anticipated that the results of both acoustic and ultrasound images of the tongue movements will be shared with others in the following ways: 1) they will be written and delivered in my students' theses; 2) they may be published in whole or in part as a journal article; and 3) they may be presented at a scholarly meeting.

Contacts

Individuals that may be contacted regarding this study include Dr. Lin at 250-721-6643 or by email at luahin@uvic.ca; Akitsugu Nogita at akitsugu@uvic.ca; or Nan Xing at nanxingme@gmail.com.

In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study, including that you understand that *you agree to meet with the researcher to participate in an ultrasound experiment and complete a questionnaire before the experiment*. Your signature also indicates that you have had the opportunity to have your questions answered by the researcher, and that you agree to participate in this research project.

Name of Participant (Print)

Signature

Date

A copy of this consent will be left with you, and a copy will be taken by the researcher.