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Research on the Effect of Anticipatory Coariticulation of Disyllabic Words in Chinese

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Abstract:- In this paper the Vowel-to-Vowel (V-to-V) coarticulatory effect in the Vowel-Consonant-Vowel (VCV) sequences is investigated, and the second formant (F_2) offset value is analyzed. Results show that, in the trans-segmental context, anticipatory coarticulation exists in Chinese. Labials may reduce the F_2 value of the adjacent vowels, so when the subsequent vowel is /u/, the F_2 offset value of the preceding vowel is comparatively small in the context of labial. However, as the degree of articulatory constraint is low for labials, when the subsequent vowel is /i/, the effect of labial can not be fully realized. The articulatory strength of aspirated consonants is great, so in the context of aspirated consonants, the effect of the subsequent vowel on the preceding one is great.

Keywords:- Coarticulation, formant, place of articulation, vowel

I. INTRODUCTION

This study involves the coarticulatory mechanism of speech signal, which refers to the modification speech sound under the influence neighboring speech segments. For example, when we pronounce ‗dean', the tongue will go from a high front vowel position for /i/ to an alveolar nasal closure for /n/, and the velum will go from closed for /i/ to open for nasal /n/. It can be imagined that one does these two movements at the same time, but actually speakers start opening the velum at the beginning of the vowel. As a result, the high front vowel overlaps with the open velum for the following nasal, and the vowel is nasalized. Coarticulation effects may be related to a specific context or the sound system of a language. In his study of the coarticulatory effect of VCV sequences in the three languages of English, Russian and Swedish, Öhman [1] found that changes in the F_2 value of the target vowel varies in different languages due to vowel contexts. He attributed the coarticulatory differences in the languages to the consonant system.

Recasens [2] also studied restrictions of consonants on vowel-to-vowel coarticulation, and he found that the V-to-V coarticulatory extents across laterals are different in Catalan, Spain and Germany, which is due to varied articulatory constraints for these laterals. With respect to coarticulation, Bladon and Al-Bamerni [3] argue that there is a property of ‗coarticulatory resistance' for sound segments, which may hinder the extent of effect of a speech sound on the adjacent segments. Recasens [4] originated the ‗degrees of articulatory constraint' (DAC) model to illustrate the coarticulatory extent of a segment on the neighboring one.

According to the DAC model, coarticulatory resistance of a sound segment may increase with DAC, that is, with the involvement of articulators in the formation of a closure and with the demands of manner of articulation. To be specific, coarticulatory resistance is small for labials as the tongue does not involve in the production of these speech sounds. Alveolopalatals, which are produced with the tongue, are more constrained than labials. Dark /l/ should be more constrained than clear /l/, front vs. back vowels exhibit systematic differences in coarticulatory resistance, and the degree of articulatory constraints is high for high vowels than the low vowels.

Some research work has been done on the coarticulation of vowels and consonants in Chinese, including study on the coarticulatory effect of voiceless fricatives in disyllabic words [5], the analysis on vowel quality in monosyllabic word with voiceless obstruent onset [6], the anticipatory coarticulatory effect on the trans-syllabic consonants in disyllabic words [7], the extent of coarticulatory effect of vowels in read speech in Mandarin [8], and the anticipatory coarticulatory extent in inter-syllabic position [9]. Results display that there are coariticulatory effect in neighboring speech sounds as well as trans-segmental condition in Chinese.

In world languages, Coarticulation is quite common, and people believe that coarticulatory model is helpful in speech technology in that it may affect the voice quality of synthesized speech. Therefore, the quality of synthetic speech will be dramatically improved if the coarticulatory model is optimal [10]. The present study aims to explore the vowel-to-vowel coarticulatory effect in disyllabic words in Mandarin. For coarticulation, there are carry-over and anticipatory ones [11], and this paper will study anticipatory coarticulatory mechanism.

II. METHODOLOGY

2.1 Speakers, stimuli and recording

The subjects are twelve university students, six male and six female, who are native speakers of Mandarin. As for the stimuli, two-syllable words are used, in the form of $C_1V_{1.}C_2V_2$, with V_2 as the _varying‘ vowel context, and V_1 the _affected‘ vowel context, which is constructed for the varying vowels to influence to affected one. The affected vowel is /i/, and regarding the varying vowel context, the vowels /i/ vs. /u/ are adopted, in order to influence the end point of the F_2 frequencies of the affected vowel. The consonant onsets of the second syllable are /b, p, d, t/, two unaspirate consonants /b/ and /d/ and two aspirated consonants /p/ and /t/. The words used in this experiment are all normally stressed, with no unstressed syllables. For example, a pair of such words in the word list are _dipi‘ and _dipu‘, which mean _land for building‘ and _shakedown‘ respectively.

For each combination, two sets of such words are adopted, so there are totally 16 words in the list (4 consonants × 2 varying vowel contexts × 2 sets).

Recording was conducted in a sound-proof room, and the acoustic signal were recorded directly into the computer with a sampling rate of 16 kHz by the recording software of Cool Edit Pro. The subjects were instructed to read the word list three times, in random order for each repetition, in normal speed, so each subject produced 48 tokens: 16 words × 3 repetitions. In total, 576 tokens were obtained for analysis (48 tokens × 12 speakers).

2.2. Procedure and measurements

1) F_2 offset value: The aim of this study is to investigate the trans-consonantal vowel to vowel coarticulatory extent in two-syllabic words, and vowel formant value is examined. The formant values are extracted by using Praat [12], and the extent of trans-consonantal coarticulatory effect is analyzed by investigating the F_2 offset value of the affected vowel. F_2 offset frequency value is obtained at the offset point of the affected vowel V_1.

Fig. 1 presents the waveform and spectrogram of _dipi‘ (land for building), where C_2 is an aspirated, labial consonant. For the purpose of analyzing the coarticulatory effect, F_2 offset value is measured at the end point of the first vowel, i.e., point _A‘ on the graph.

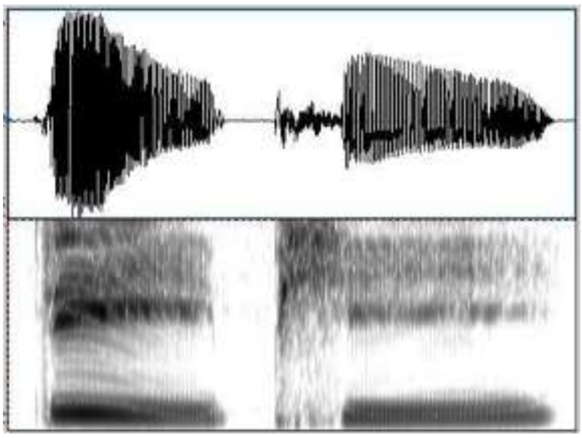


Fig. 1 Waveform and spectrogram of ‘dipi’

2) F_2 delta: For the purpose of comparing the extent of coarticulatory effects in different consonant contexts, in addition to F_2 offset values, their differences triggered by the varying V_2 contexts are also

computed. Coarticulation effects owing to varying V_2 contexts are displayed by F_2 delta values got at the V_1 F_2 offset point, and F_2 delta (Hz) is obtained by calculating the difference in offset frequencies of the affected vowel in each word pair, as is shown in formula (1),

$$\Delta F_2 = F_{2i} - F_{2u} \qquad (1)$$

In (1), F_{2i} and F_{2u} refer to the V_1 F_2 offset values in front of vowel /i/ and /u/ respectively, and ΔF_2 is the F_2 delta at the offset point of V_1.

Fig. 2 shows the F_2 contours of the word sequence pair ‗dipi' (land for building) and ‗dipu' (shakedown), with the F_2 contour of ‗dipi' in solid line, and that of ‗dipu' in dashed line. In this word sequence pair, for the varying vowel context, the F_2 value of /i/ is high and that of /u/ is low. If V_1 F_2 offset values differ in this word pair, it is rational to attribute the frequency difference value to the high vs. low F_2 contexts in the following V_2. The greater the F_2 delta value is, the greater the coarticulatory effect of the following V_2 is on the preceding V_1.

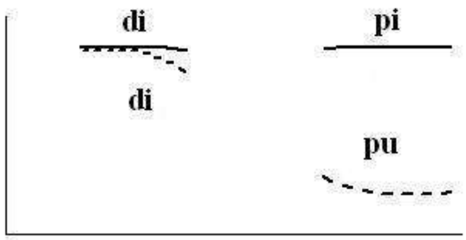


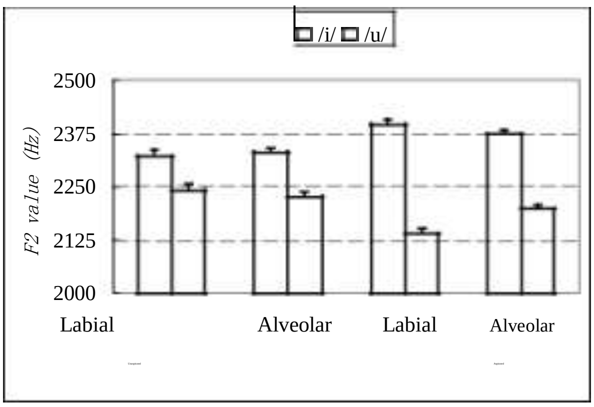
Fig. 2 F_2 contours of the sequence pair 'dipi' and 'dipu', with the former in solid line, and the latter in dashed line

A repeated measures ANOVA was conducted with two main factors— aspiration (unaspirated, aspirated) and place of articulation (labial, alveolar).

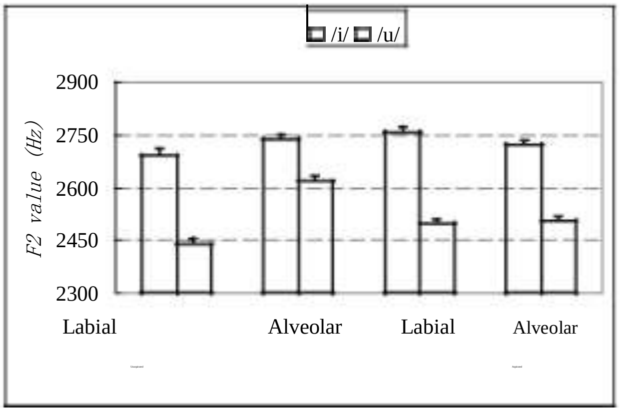
III. RESULTS

3.1 F_2 value

Fig. 3 displays the F_2 offset values for both male speakers (Fig. 3a) and female speakers (Fig. 3b), broken down by conditions of aspiration, place of articulation and varying vowel contexts. The varying vowel contexts are shown by /i/ and /u/, which stand for the varying vowel contexts of /i/ and /u/ respectively. It is shown from repeated measures ANOVA results that, in respect to main effect, significant effects exist for the varying vowel context: $F(1, 71) = 228$, $p < 0.001$, with V_1 F_2 offset values larger in the vowel context of /i/ than of /u/. However, there are no significant effect for place of articulation and aspiration on the F_2 offset values of V_1, place of articulation: $F(1, 71) = 2.46$, $p = 0.121$; aspiration: $F(1, 71) = 0.021$, $p = 0.884$.



(a) F_2 values of male speakers



(b) F_2 values of female speakers

Fig. 3 F_2 offset values for male speakers (a) and female speakers (b), broken down by the contexts of aspiration, place of articulation and changing vowel

Further observation shows that there is significant place of articulation × changing vowel interactive effect: $F(1, 71) = 6.97$, $p = 0.01$, and the aspiration × changing vowel interactive effect is also significant: $F(1, 71) = 15.2$, $p < 0.001$. In the next subsections, the effects will be displayed in detail.

3.1.1 The effect of place of articulation 1) In the context of /i/

When the vowel in the second syllable is /i/, repeated measures ANOVA results show that there is no significant effect for place of articulation on the V_1 F_2 offset values: $F(1, 143) = 0.000$, $p = 0.986$. There is no significant difference on coarticulation between the labial and alveolar contexts.

2) In the context of /u/

However, in the context of varying vowel /u/, it is shown from ANOVA results that the effect of place of articulation on the V_1 F_2 offset values is significant: $F(1, 143) = 5.62$, $p = 0.019$, with V_1 F_2 offset values in the alveolar context greater than that in the labial context.

3.1.2 The effect of aspiration

1) In the context of /i/

In regard to the effect of aspiration on the coarticulation of the V_1 F_2 offset values, in the context of /i/, it is shown from ANOVA results that there is significant effect for it: $F(1, 143) = 11.5$, $p = 0.001$, with V_1 F_2 offset values greater in the context of aspirated consonants than that in the unaspirated context.

2) In the context of /u/

In the case of the subsequent vowel as /u/, ANOVA results show that there is also significant effect of aspiration on the V_1 F_2 offset values: $F(1, 143) = 4.44$, $p = 0.037$, with V_1 F_2 offset values larger preceding the unaspirated consonants than preceding the aspirated ones.

In order the present the coarticulatory effect under various consonant contexts in detail, F_2 delta value will be investigated in the subsequent subsection. To be specific, the coarticulatory extent under the contexts of place of articulation and aspiration will be displayed.

3.2 F_2 delta value

Fig. 4 shows the F_2 delta values under the effects of place of articulation and aspiration, and Table 1 presents the F_2 delta means and ANOVA results for the main effects. From Table 1 it is shown that, in terms of overall main effect, significant effect exist for both place of articulation and aspiration, with the coarticulatory effect in the labial contexts greater than that in the alveolar contexts, and the effect of aspirated consonant contexts greater than that of the unaspirated ones.

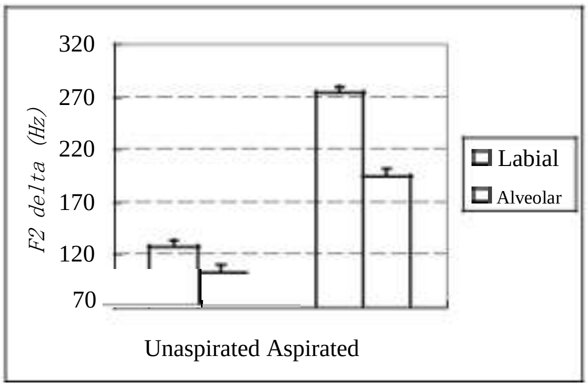


Fig. 4 F_2 delta under the effects of place of articulation and aspiration

Table 1 F_2 delta means (in Hz) and statistical results for the main effects

		Mean	**Statistical result**
Place of articulation	Labial	200.4	**F(1, 71) = 5.25, p = 0.025**
	Alveolar	148.3	
Aspiration	Unaspirated	114.9	**F(1, 71) = 28.7, p < 0.001**
	Aspirated	**233.7**	

Regarding the interactive effects, results show that the place of articulation × aspiration interaction is not significant: $F(1, 71) = 2.02$, $p = 0.159$. The coarticulatory effects on the various level of the two factors are roughly consistent with each other.

IV. DISCUSSION

Results in the previous section show that, when V_1 F_2 offset value is investigated, the effect of the varying vowel context on it is significant, with value at F_2 offset point preceding vowel /i/ greater than that preceding /u/. The aim of this study is to investigate the anticipatory coarticulatory effect of the following V_2 on the forgoing V_1, with the varying vowels of V_2 as /i/ and /u/. As is mentioned above, the F_2 value of /i/ is high, while that of /u/ is low. The V_1 F_2 offset values are significantly different when preceding /i/ vs. /u/. This implies that trans-consonantal vowel to vowel anticipatory effect exists in Chinese.

When the vowel in the second syllable is /u/, there is significant effect of place of articulation on the V_1 F_2 offset value, with that before alveolars greater than before labials, which shows that the effect of place of articulation is significant for coarticulation. Generally speaking, the F_2 value of a vowel will be reduced when the adjacent consonant is a labial, while increased in the context of an alveolar [9]. Chen [7] investigated the extent of coarticulation between neighboring as well as trans-segmental vowels, and her results confirmed these properties of labials and alveolars. The F_2 vlaue of vowel /u/ is low, so under this effect, the V_1 F_2 offset value will be decreased. As the same time, since the F_2 value may also be reduced when neighboring labials, under these dual effects, the V_1 F_2 offset value will be small in the context of labials. Therefore, in the context of vowel /u/, the V_1 F_2 offset value is higher preceding alveolars than preceding labials.

However, when the following vowel is /i/, there is no significant difference between the V_1 F_2 offset values when preceding labials or alveolars. The reason for this is as follow, the F_2 value of a vowel may become high in the context of alveolars. In this context, since both the preceding and the following vowels are /i/, and the F_2 value of /i/ is high, there will not be great change for the V_1 F_2 offset value. On the other hand, in the context of labials, as labials may reduce the F_2 value of adjacent vowels, the V_1 F_2 offset value should become low. But as the following vowel is /i/, and the F_2 value of /i/ is high, in this case, the V_1 F_2 offset value will not change a lot. Therefore, in the context of /i/, the effect of place of articulation is restrained, and this is also partially because that the degree of articulatory constraint of the labial is low.

The DAC model [13] foretells that in the VCV sequences, an increase in the degree of constraint for the consonant should produce an increase in the strength of the C-to-V effects and a reduction in the prominence of the V-to-C and V-to-V effect. In accordance to the DAC model, the diversity in the involvement of the articulators in the pronunciation of different obstruents leads to the variation of the degree of articulatory constrait. Obstruents, particularly alveolopalatals, that maximally engage the tongue dorsum for the occlusion gesture, would reduce vowel effects, that is, stops like /d/ and /t/ exhibit reduced extents of V-to-V coarticulatory effect.

Concerning coarticulation, coarticulatory sensitivity, which is the scale and temporal degree of the coarticulatory effect for a given articulator, is proved to be conversely related to the extent of articulatory constrait: highly constrained sound segments are generally more resistant to coarticulation than those stipulated for a lower degree of articulatory constraint, and thus less sensitive to coarticulatory effect from neighboring segments. The model also foretells that coarticulatory domination is actually related to the degree of articulatory constraint: sound segments with high DAC value and coarticulatory resistant usually have great coarticulatory effects on the neighboring sound segments.

It is shown that the degree of articulatory constraint of a labial is small, with its effect on the V_1 F_2 offset value comparatively small, so at the same time, its coarticulatory resistence is also low. On the contrary, since the effect of the following vowel is great when it is /i/, the V_1 F_2 offset value will not change a lot. Therefore, when the subsequent vowel is /i/, there is no significant difference for the V_1 F_2 offset values under the labial and alveolar conditions.

Regarding the effect of aspiration, results in the foregoing section displays that, in the context of following vowel /i/, the V_1 F_2 offset value is greater in the context of aspirated consonants than of the unaspirated ones, which is owing to the great articulatory prominance of aspirated obstruents. Generally speaking, sound segments may be classified into two groups: _fortis' and _lenis', which refer to consonants that are pronounced with greater and lesser energy respectively, such as in energy used, articulation, etc. The terms of fortis and lenis were coined as less misleading words to mean consonantal contrasts in languages that do not apply actual vocal fold vibration in their voiced consonants, but instead involved amounts of articulatory strength. For example, in English, there are fortis consonants, as in _come' and _put' that exhibit a longer obstruent closure and shorter preceding vowels than their lenis counterparts, as in _grass' and _bed'. In Chinese, aspirated consonants are fortis, while unaspirated ones are lenis.

As the aspirated consonants in Chinese are fortis, their articulatory prominence is consequently great. Generally speaking, consonants with great articulatory strength tend to employ great effect on the preceding vowels. In Chinese, consonants and vowels are combined into one unit: the syllable. Syllables with consonants of high articulatory strength may have great effect on the preceding vowel. As a result, the anticipatory coarticulatory effect is great when the C_2 is aspirated consonant. The F_2 value of vowel /i/ is high, so in this case, the V_1 F_2 offset value may be comparative high. As in the context of aspirated consonants, the anticipatory coarticulatory effect is relatively great, the V_1 F_2 offset value will be higher in the context of aspirated consonants than in the unaspirated context.

However, coming to the context of vowel /u/, it is not the case, i.e., the V_1 F_2 offset value is higher in the unaspirated context than in the aspirated context, which is also due to the high articulatory strength of aspirated consonants. The articulatory strength of an aspiraed consonant is comparatively high, therefore, when the consonant combines into syllable with the following vowel, the effect of the syllable on the foregoing vowel will also be great. Since the F_2 value of vowel /u/ is low, the V_1 F_2 offset value in the context of /u/ will be consequently low. The anticipatory coarticulatory effect is comparatively great in the context of aspirated consonants, therefore, the V_1 F_2 offset value is higher in the unaspirated context than in the aspirated context.

As for the F_2 delta values, when main effects are analyzed, there is significant effect for place of articulation, with the effect in the labial contexts greater than that in the alveolar context. According to the DAC model, the degree of articulatory constraint of alveolars is higher than that of labials, so the effect of trans-consonantal coarticulation will be greater in the context of labials than of alveolars. In this study, it is shown that the coarticulatory pattern is consistent to the DAC model: as far as main effect is concerned, the coarticulatory effect is greater in the context of labials than that of alveolar. The coarticulatory resistant for alveolars is comparatively great, which is in line with the DAC model.

In regard to the effect of aspiration of C_2, it is shown from the results in the previous section that coarticlation effect is greater in the context of aspirated consonant than that of unaspirated one, which is due to the high articulatory strength of aspirated consonants. The articulatory strength of the aspirated consonant is high, so its effect on the preceding vowel is great. In Chinese, consonants and vowels are combined into syllable. Syllables with consonants of high articulatory strength will have high effect on the foregoing vowel. Therefore, coarticulatory effect is greater in the aspirated context than in the unaspirated context.

V. CONCLUSION

In this experiment, the Vowel-to-Vowel coarticulatory effect in the VCV sequences is investigated, and it is shown that there is significant difference between the V_1 F_2 offset values in the contexts of following vowels /i/ vs. /u/, which implies that trans-segmental anticipatory coarticulatory effect exists in Chinese. Since labials may reduce the F_2 values of adjacent vowels, in the context of vowel /u/, the V_1 F_2 offset value is higher in the context of alveolar than of labial. The degree of articulatory constraint of a labial is low, so in the context of vowel /i/, the effect of labial is restraind, and there is no significant effect of place of articulation on the preceding V_1 F_2 offset value. As the articulatory strength of aspirated stop is high, the effect is great when C_2 is aspirated consonant. The degree of articulatory constraint of alveolar is high, therefore, the trans-consonantal coarticulatory effect in the labial context is greater than in the alveolar context, which is consistent to the DAC model.

This study is of great significance in speech engineering. In the practice of speech synthesis, the extent of trans-consonantal coarticulation must be taken into consideration. The effect of coarticulation in the context of labial exceeds that of alveolar, and the extent of aspirated consonants exceeds that of unaspirated ones, therefore, more attention should be taken in these contexts. However, in some case, the difference of coarticulatory effects can be neglected, as it sometimes disappears. Therefore, this study is helpful in speech engineering technology.

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