Degree of Articulatory Dispersion: An Introduction to a Model of Coarticulation

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Abstract. The purpose of the study is to introduce a new Model of Coarticulation, namely, Degree of Articulatory Dispersion. This paper reviews the Models of Coarticulation, and then the validity of the Degree of Articulatory Dispersion is proved by finding the correlation between the dispersion of DAD and the slope of LEM in the four groups of Monguor consonants classified by the manner of articulation. The finding shows that there is a significant negative correlation between the dispersion of DAD and the slope of LEM. Therefore, Degree of Articulatory Dispersion can be a valid Model of Coarticulation to measure the degree of coarticulation.

1. Introduction
In speech, segments do not exist independently. When different segments are grouped together, the pronunciation will affect each other and change. The various parts of the vocal organs are constantly in motion, and the postures of the adjacent segments are superimposed on each other, so that at any point in time, the shape of the vocal tract, especially the tongue, is always influenced by the anterior and posterior segments. This is what coarticulation describes. Various phonetic changes, such as assimilation, dissimilation, weakening, insertion, deletion, metathesis and substitution, are almost related to coarticulation.

Generally speaking, coarticulation refers to the phenomenon that conceptually independent speech sounds are influenced by the speech sounds before or after them. From the perspective of directionality, there are two kinds of coarticulation: (1) carryover coarticulation —— as a result of a certain speech sound being influenced by its later speech sound, and (2) anticipatory coarticulation —— as a result of a certain speech sound being influenced by its former speech sound. In fact, the two kinds of coarticulation may occur in the same word because vowels and consonants interact with each other in a word (Hardcastle & Hewlett, 2006) [1].

Some theories of coarticulation are used to explain the origin, characteristics and functions of coarticulation, and to explain how listeners overcome the variation of coarticulation and recover the implied information (Farnetani & Recasens, 2013) [2]. Speech Economy Theory (Lindblom, 1989) [3] argued that, as the most ideal form of human communication, speech faces two dilemmas: the more successful delivery of information and the less difficulty to transmit information. Therefore, the output of speech is always a variable process. The listener needs to get accurate information, but the speaker does not communicate clearly because of the less effort. In situations where the speaker needs to articulate clearly, the speaker will over-articulate; otherwise, the speaker will use the economy principle and under-articulate. Lindblom and Sussman (2012) [4] saw this phenomenon as a continuum with two endpoints: hyper-speech and hypo-speech. Coarticulation is at the center of this continuum,
as the degree of perceptual contrast decreases and the degree of coarticulation increases from the hyper-speech to the hypo-speech. “Locus Equations Model” was one of the research results under the guidance of Speech Economy Theory.

2. Models of Coarticulation

2.1. Coarticulation Resistance
Many models have been developed to explain the degree of coarticulation. Bladon and Al-Bamerni (1976) [5] put forward the concept of “Coarticulation Resistance.” They thought that the pronunciation of a sound is relatively stable because of its inherent resistance to adjacent segments. According to the characteristic of coarticulation resistance, the sound with high coarticulation resistance will resist the influence of adjacent segments, and conversely, it will influence adjacent segments.

2.2. Model of Degree of Articulatory Constraint
Recasens, Pallarès and Fontdevila (1997) [6] proposed a “Model of Degree of Articulatory Constraint,” which explains the degree of coarticulation according to the value of the articulation constraint. According to this model, for a VCV sequence, the higher the coarticulation resistance of a consonant, the greater the influence on the front and back vowel, and the weaker the influence between the vowels (Recasens & Rodríguez, 2016) [7].

2.3. Locus Equations Model
Another model used to measure coarticulation resistance in acoustic studies is Locus Equations Model (LEM) (Brancazio & Fowler, 1998; Lindblom & Sussman, 2012) [8] [4]. The LEM is a linear regression prediction model, which is implemented by predicting the value of the second formant from the initial value of a vowel to the target value of a vowel under the influence of a consonant. The degree of coarticulation of a consonant is determined by its position and by the circumstances in which all possible consonants are placed. The slope and intercept of the Locus Equations vary with different sound places of consonants. According to Fowler (1994) [9], lip sounds have the highest slope of the Locus Equations and the lowest coarticulation resistance, while dental sounds have the highest coarticulation resistance and the lowest slope of the Locus Equations. Research by Iskarous et al. (2010) [10] showed that the Locus Equations predict the coarticulation resistance based on linear regression, with the coarticulation of a consonant more likely to be predicted from an adjacent vowel, then the slope of the equation and the coarticulation resistance of the consonant to be smaller.

2.4. Jackson-Singampalli Statistical Identification Model
Jackson and Singampalli (2009) [11] proposed a “Jackson-Singampalli Statistical Identification Model” to measure coarticulation resistance, which is based on the model proposed by Recasens (1985) [12] and Recasens and Espinosa (2009) [13]. The Statistical Identification Model shows that the standard deviation or the range of the formants of a segment can show its constraint degree. A small standard deviation or range means a high constraint of the segment, whereas a large standard deviation or range means a low constraint of the segment. Therefore, the smaller the standard deviation or range of a segment is, the greater the coarticulation resistance becomes.

2.5. Coarticulation / Invariance Scale
Based on Model of Degree of Articulatory Constraint, Locus Equations Model, and Jackson-Singampalli Statistical Identification Model, Iskarous et al. (2013) [14] proposed a “Coarticulation / Invariance Scale.” One end of the scale is coarticulation, and the other end is invariance. The amount of articulation information between adjacent segments is measured by Mutual Information. The large Mutual Information means that the sound scale of a segment is at the coarticulation end, and the small Mutual Information means that the sound scale of a segment is at the invariable end. There is a close
relationship between the Locus Equations Model and Coarticulation / Invariance Scale, which are widely used in the study of acoustic coarticulation.

3. Research method

3.1. Source of Corpus

The data in this study come from an acoustic parameter database of the Monguor speech built by the author. The Monguor words of elaborate record come from those daily used by Monguor people of Huzhu County in Qinhai Province and Tianzhu County in Gansu Province of China. The words retrieved from the database for this study are those of containing consonant-vowel (CV) syllables and consonant-vowel-consonant (CVC) syllables.

3.2. Speech Signal Collection

In consideration of language stability, the informants for the study are thirteen male speakers, about 40 to 60. The informants are teachers in local primary or junior schools. This study employs a Dell Notebook, a microphone of Behringer, and a sound card of YAMAHA Steinberg as the recording equipment. The sound is recorded in a recording studio with a sampling rate 44.1 kHz and resolution ratio 16 bits. The recording is saved with *.wav. Each word is read three times by each speaker.

3.3. Research Questions

This study will address the following questions:

1. What is the model of Degree of Articulatory Dispersion?
2. What is the correlation between the dispersion of Degree of Articulatory Dispersion and the slope of Locus Equations Model?

4. Introduction to Degree of Articulatory Dispersion

This paper proposes a new model of Degree of Articulatory Dispersion (DAD) to measure the coarticulation between adjacent segments by means of dispersion. The dispersion in this paper refers to the statistical dispersion, which is used to measure the dispersion of a set of data.

The parameter of coefficient of dispersion (COD) is applied in this study for the measurement of DAD. COD is the ratio of the average absolute deviation from the median to the median of the data. The formula of COD is:

\[ \text{COD} = \frac{\sum |R_i - \bar{R}|}{N \times M} \]

in which R is the ratio of standard deviations (SD) of F2\text{target} to F2\text{onset}; R_i is each ratio value; \bar{R} is the mean of all ratio values; N is the number of the sample; and M is the median of all ratio values. F2 refers to the second formant of a segment. In this study, COD is calculated by putting the values of F2\text{target} and F2\text{onset} into SPSS24.0.

The idea of the ratio variable \( R = SD(\text{F2}_{\text{onset}}) / SD(\text{F2}_{\text{target}}) \) is that the F2 of a sound is not a fixed value because if the same person pronounces the same sound several times, different F2 values will appear, but that the range of standard deviations from these measurements is smaller, so the standard deviation is relatively stable. Therefore, it is more objective to consider how much a sound is affected by converting an unstable value into a stable one. For example, if the F2\text{target} of a vowel is stable, the standard deviation of the F2\text{target} is small, and if the standard deviation of the F2\text{onset} is large when the vowel is preceded by a different consonant, the ratio R will become large. The large ratio R explains the greater deviation from F2\text{target} to F2\text{onset}. The idea of COD comes from the fact that the absolute deviation of the ratio variable and the median of the ratio variable are taken into account when considering the degree of dispersion.
5. Correlation between DAD and LEM

The greater dispersion of a consonant’s coarticulation means that the consonant is more easily influenced by its front or back vowels, so the degree of coarticulation between the consonant and the vowel(s) is lower. Conversely, previous studies have shown that, the large slope of the Locus Equations for a consonant coarticulation means that the consonant has a higher degree of coarticulation with its front or back vowels. Based on the meaning of the dispersion and the slope of the Locus Equations, this study proposes that the coarticulation dispersion of a consonant should have an inverse relationship with the slope of the Locus Equations. That is to say, the large coarticulation dispersion of a consonant means the small slope of the Locus Equations. In this part, the correlation analysis is used to test this hypothesis. If this hypothesis is true, the dispersion can be used as an index to measure the degree of coarticulation.

Table 1 shows the correlation between the dispersion of DAD and the slope of LEM in the four groups of Monguor consonants. Except in the nasals /m/, /n/, /ŋ/, and lateral /l/ with the correlation coefficient $r = -0.481$, $p = 0.51 > 0.05$, there are significant negative correlations between the dispersion and the slope in the plosives /p/, /t/, /k/, /pʰ/, /tʰ/, and /kʰ/ with the correlation coefficient $r = -0.574$, $p = 0.000 < 0.01$, in the affricates /ʦ/, /tʂ/, /ɕ/, /ʨ/, /ʦʰ/, /tʂʰ/, and /ʨʰ/ with the correlation coefficient $r = -0.471$, $p = 0.009 < 0.01$, and in the fricatives /ʂ/, /s/, /ɕ/, /f/, /x/, /ʐ/, /j/, and /w/ with the correlation coefficient $r = -0.534$, $p = 0.002 < 0.01$.

Table 1. Correlation between the dispersion and the slope.

| Consonants       | Number | Coefficient | P value |
|------------------|--------|-------------|---------|
| Plosives         | 35     | -0.574**    | 0.000   |
| Affricates       | 30     | -0.471**    | 0.009   |
| Fricatives       | 30     | -0.534**    | 0.002   |
| Nasals and lateral | 17  | -0.481      | 0.051   |
| Total            | 112    | -0.506**    | 0.000   |

**significant at the 0.01 level.

As a whole, there is a significant negative correlation between the dispersion of DAD and the slope of LEM in all Monguor consonants with the correlation coefficient $r = -0.506$, $p = 0.000 < 0.01$. The scatter plot (Figure 1) of the Correlation between the dispersion of DAD and the slope of LEM in all Monguor consonants shows that the data are scattered from the upper left to the lower right, that is to say, the dispersion tends to decrease when the slope becomes from small to large. This relationship is shown by a fitting line ($R^2 = 0.256$), which shows a significant negative correlation between the dispersion of DAD and the slope of LEM in all Monguor consonants.

![Figure 1. Scatter plot of the Correlation between the dispersion and the slope](image)

6. Summary

Degree of Articulatory Dispersion, together with Coarticulation Resistance, Model of Degree of Articulatory Constraint, Locus Equations Model, and Jackson-Singampalli Statistical Identification
Model, and Coarticulation / Invariance Scale, constitute the family of Models of Coarticulation. The significant negative correlation between the dispersion of DAD and the slope of LEM in all Monguor consonants shows that the dispersion of DAD, together with the slope of LEM, the blending strength (Fowler & Saltzman, 1993) [15], and constraint degree, can be an evaluation index to measure the degree of coarticulation. In this research, the group of Monguor consonants (plosives, affricates, fricatives, nasals and lateral) is classified by the manner of articulation. Actually, the group of Monguor consonants can also be classified by the place of articulation, namely, labials /p/, /pʰ/, /f/, and /m/, apicals /t/, /tʰ/, /s/, /sʰ/, /tʃ/, /tʃʰ/, /z/, /zʰ/, /n/, and /l/, palatal-velar sounds /k/, /kʰ/, /G/, /w/, /wʰ/, /ɑ̃/, /ɔ̃/, and /ŋ/. Further studies on the correlation between the dispersion of DAD and the slope of LEM can be conducted by means of the groups of Monguor consonants classified by the place of articulation.

Actually, the experimental verification of the model of DAD in Monguor Language has been conducted by Zhang in many papers. Zhang (2017a) [16] discussed the coarticulatory dispersion of places of articulation of affricates, the coarticulatory dispersion of voiced and voiceless affricates, and the main effects of places of articulation of affricates, voiced and voiceless affricates on coarticulatory dispersion. On the base of acoustic parameter database of the Monguor speech, Zhang (2017b) [17] discussed the differences in the coarticulatory dispersions between the nasal vowels [ã] and [5] and the locus equation slopes of the unaspirated stops by the following nasal vowels [ã] and [5]. Zhang (2018) [18] discussed which acoustic features of consonants have significant linear relation with coarticulation dispersion in Monguor language. The acoustic features include F1, F2 and F3 of vowels combined with each consonant, the length and intensity of consonants themselves. Zhang (2019) [19] concluded that both in the CV structure and in the VC structure in Monguor Language, the monophthongs with the tongue back, the tongue high, and the lip round are more likely to be influenced by their preceding or subsequent consonants. In addition, the lower the tongue is, the smaller the coarticulation COD of vowels is.

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