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Consonant Features in Mandarin Speech Errors*

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This paper examines the psychological validity of hierarchies in consonantal features based on analyses of naturally occurring speech errors in Mandarin spoken in Taiwan. Differences in consonant pairs that interacted in speech errors involve five features: place, voice onset time, continuancy, frication, and nasality in different proportions. Most errors involve consonant pairs differing in only one feature, and there is a monotonic decrease as the number of feature differences increases. This suggests that consonant similarity in terms of shared features affects the frequency with which two segments are mutually involved in speech errors. Place of articulation is the feature most often violated in speech errors whereas nasality is violated the least often. Such a hierarchy of feature distribution may have some cross-linguistic validity and can be partially explained in Optimality Theory in which faithfulness to manner is ranked higher than faithfulness to place predicting more error violations in place features.

Key words: speech errors, phonetic similarities, consonant features, Mandarin

1. Introduction

Phonetic features have long been regarded as important phonological units in speech production planning and execution. In traditional phonological theory, features are regarded as unordered matrices in strict succession in linear frameworks in the phonological representation (Jakobson & Halle 1956, Jakobson 1968). However, when the traditional linear representation could not fully account for phonological processes occurring in a wide range of languages, such as tonal phenomena (e.g., Goldsmith 1976, Clements & Ford 1979, Yip 1980, among others), vowel harmony (Clements 1976) and nonconcatenative morphology (McCarthy 1979), phonological representation then came to be regarded as consisting of a single feature matrix that comprises a set of unordered distinctive features in the current phonological theory. The problems raised by these phenomena suggest that segments are comprised of feature bundles, and features are treated as the minimal and basic units of phonological representation, organized into a geometric hierarchy on autonomous phonological tiers grouped under the nodes according to their natural classes. The

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above framework is based on a rule-based system, and in recent years, a constraint-based perspective provides a means for better investigating interactions between different types of constraints in speech-error studies, and for viewing such error distributions as a constraint-satisfaction problem (e.g., Goldrick 2006, 2011, Goldrick et al. 2011, Goldrick & Chu 2014). This approach and related approaches in Optimality Theory provide a framework for understanding the error distribution in terms of differently ranked constraints and for exploring the nature of constraint interactions in speech production. For instance, the major class features in differentiating consonants involve voicing, place of articulation, and manner of articulation, and given a highly ranked constraint, faithfulness to manner features usually take precedence over faithfulness to voicing or place features.[1]

Whereas segments have long been regarded as the fundamental phonological units in phonological theories, current phonological theories ensure the status of the independent existence of features. Thus, the purpose of the present paper is to expand the discussion by including a psycholinguistic perspective and to provide more evidence with regard to the independent existence of consonant features in Mandarin by examining a corpus of spontaneous speech-error data.

Speech errors, one-time errors in speaking that result from an error during the speech production planning process, have a long tradition of use in testing phonological hypotheses and theories. In addition, speech-error studies over the past several decades have used the patterns and constraints observed in the extensive collection of errors to argue both for the validity of phonological units as processing units and also for particular phonological theories or cognitive processing models (e.g., Fromkin 1973a, 1980, Shattuck-Hufnagel 1979, Cutler 1982, Stemberger 1983, Dell 1984, Berg 1987, 2004, Levelt 1989, Bock & Levelt 1994, among many others).

The majority of consonantal errors committed as speech errors have been found to be phoneme substitution errors. Most researchers working on speech error studies have found that consonants are more likely to mutually interact with each other in errors if they are phonetically similar (e.g., Fromkin 1973b, MacKay 1973, Nooteboom 1973, Van den Broecke & Goldstein 1980, Levitt & Healy 1985, Stemberger 1989, Jaeger 1992, 2004, Frisch 1997). They have discussed the role of features in terms of error generation and worked on segment similarity based on the number of shared features. When substitution errors are analyzed in terms of phonologically distinctive features, the substituted phoneme usually differs from the target phoneme by only one feature. How segmental errors can be displayed as a kind

[1] I would like to thank one of the reviewers for pointing out the ranking constraints in relation to speech errors.

of featural organization is an area examined through the study of consonant substitution and exchange errors.

Speech-error research in the past several decades has primarily been done on English and related languages (Dutch and German), and therefore there are few reports in the literature which bear on the issue of the psychological validity of feature hierarchies of other languages, particularly Asian languages. A few studies involving speech errors have been done recently in Mandarin. These include Moster (1991), Chen (1993), and Shen (1993) all on Mandarin speech-error classification, Wan (1996), Wan & Jaeger (1998), and Chen (1999) on Mandarin tone, Wan (1997) on Mandarin glides, Yang (1997) on Mandarin psycholinguistic models, Wan (1999) on Mandarin phonology, Wan (2002) on Mandarin syllables, Wan & Jaeger (2003) on Mandarin vowels, and Wan (2007a, 2007b) on models of speech production in Mandarin. However, none of the above studies has ever discussed the issue with regard to how phonetic similarity within consonants can consequently trigger a mutual interaction resulting in errors.

The present study adopts the feature system proposed by Van den Broecke & Goldstein (1980) to examine a naturally-occurring corpus of 292 speech errors (all involving contextual single consonant substitution and exchange) drawn from native speakers of Mandarin in Taiwan, and after examination to provide some evidence of the psychological validity of hierarchies and rank order in consonantal features. Questions to be explored in regard to feature distributions and hierarchies in terms of speech errors in Mandarin include such issues as whether all of the contextual single-consonant substitution and exchange errors in the Mandarin corpus display any phonetic similarity between target and source segments, and whether or not the hierarchy and rank order of feature distribution in Mandarin have any psychological validity in comparison with cross-linguistic findings. The two main areas will be interpreted as follows:

1) In whole segments involving contextual single-consonant substitution and exchange errors in Mandarin, do these segmental errors display any phonetic similarity between their target and source segments? More specifically, how many feature differences are there between target and source segments? The rationale for this question is that it is well known that, in English, consonants are more likely to mutually interact with each other in speech errors if they are phonetically similar (e.g., Fromkin 1973b, MacKay 1973, Nooteboom 1973, Van den Broecke & Goldstein 1980, Levitt & Healy 1985, Stemberger 1989, Jaeger 1992, 2004, Frisch 1997).

2) If the target and source segments that mutually interact with each other in errors share some phonetic similarities, is there any hierarchy and rank order of feature distribution in Mandarin? That is, which type of feature is violated the most often in Mandarin speech errors? The rationale for this question is that a number of researchers have found an overall hierarchy of feature involvement in speech errors and the feature that is violated the most often is place of articulation whereas the nasality feature is the one violated least often (Van den Broecke & Goldstein 1980, Jaeger 1992, 2004).

This paper is organized as follows. The following section will lay out the facts and discuss relevant issues with regard to consonant substitution errors in English. Section three will present the methodology for the collection and analysis of speech errors in detail. Section four will present findings and results in relation to the above research questions. Section five will summarize the study and will discuss the analysis supported by the study in detail.

2. Overview

The Mandarin dialect being studied here includes the following 25 surface consonant phones.

Table 1. Mandarin consonants

Place of articulation / Manner of articulation	Bilabial	Labio-dental	Dental	Retroflex	Palatal	Velar
Plosive Unaspirated	p		t			k
Plosive Aspirated	p^{h}		t^{h}			k^{h}
Fricative		f	s	ʂ/ʐ	ɕ	x
Affricate Unaspirated			ts	tʂ	tɕ^{h}	
Affricate Aspirated			ts^{h}	tʂ^{h}	tɕ^{h}	
Nasal	m		n			ŋ
Liquid			l			
Glide	w				j/ɥ	w

Mandarin has 25 consonant phones. There is a two-way contrast of aspiration for the plosives and affricates, e.g., [p] vs. [pʰ], [ts] vs. [tsʰ], and there is a two-way contrast of voicing for the retroflexed fricatives, i.e., [ʂ] vs. [ʐ]. The remaining fricatives are voiceless unaspirated. The sonorants are all voiced. In Mandarin, as with CV sequences, there are strict co-occurrence patterns with CG sequences in onsets. The contextual occurrences of these consonant phones are given in Table 2.

Table 2. Possible co-occurrence of Mandarin consonants

	Bilabial	Labio-dental	Dental	Retroflexed	Palatal	Velar
Plosive Unaspirated	pj, pw		tj, tw			*kj, kw
Plosive Aspirated	pʰj,pʰw		tʰj, tʰw			*kʰj, kʰw
Fricative		*fj, *fw	*sj, sw	*ʂj, ʂw *ʐj, ʐw	ɕj, ɕɥ, *ɕw	*xj, xw
Affricate Unaspirated			*tsj, tsw	*tʂj, tʂw	tɕj, tɕɥ * tɕw	
Affricate Aspirated			*tsʰj, tsʰw	*tʂʰj, tʂʰw	tɕʰj, tɕʰɥ * tɕʰw	
Nasal	mj, mw		nj, nɥ, nw			*ŋj, *ŋw
Liquid			lj, lɥ, lw			

As can be seen from Table 2, labial and dental plosives and sonorants can occur before the glide [j,w] and dental sonorants can also occur before [ɥ]. However, palatal affricates/fricatives can occur only before high front glides [j,ɥ], whereas dental, retroflexed, and velar affricates/fricatives can occur only before [w]. The segment /f/ cannot co-occur with glides and [ŋ] does not occur in onsets.

As for feature dimensions, in terms of phonetic features in speech errors, defining whether one segment is phonetically similar to the other is done by looking at the number of shared features in the consonant pair between target and source segments. The choice of one feature system or the other can certainly produce a different analysis. Chomsky & Halle (1968) in their classic monograph proposed a featural system that was based on extensive linguistic analysis and has been a standard in linguistics for many years. However, it has been found that theoretically motivated linguistic features cannot provide empirically adequate measures of the similarities between phonemes in perceptual, production and psycholinguistic studies (e.g., Miller

& Nicely 1955, Wicklegren 1965, 1966, Luce 1986, Goldinger, Luce & Pisoni 1989, Bailey & Hahn 2004).

A majority of studies have used the similar major class features involving voicing, place of articulation, and manner of articulation. Van den Brocke & Goldstein (1980) and Jaeger (1992, 2004) have developed feature systems from multi-dimensional scaling procedures that capture the feature dimensions governing phonetic similarity in Germanic languages. After comparing a number of feature systems, Van den Broecke & Goldstein (1980) set up multi-dimensional configurations for English and German based on speech-error features that yielded a set of five phonetic features that seemed to underlie the pattern of errors. Levitt & Healy (1985), in their experimental speech-error data, found that segment similarity emerging as a significant effect is best demonstrated by the feature system proposed by Van den Broecke & Goldstein (1980). Jaeger (1992, 2004) also adopted a similar feature system incorporated from children's speech errors in English. These procedures take all the pairings of consonants that are involved in errors, and look at the frequency with which any two consonants interact. One might find that a five-feature system might not be necessary to account for the speech error data. However, in speech-error studies, all these researchers agree that only a subset of phonetic features necessary for accounting for the phonological patterns of a language are relevant during on-line speech production planning. Based on such cross-linguistic studies, a similar feature system for Mandarin will be developed.

The cross-linguistic spontaneously occurring error corpora that Van den Broecke & Goldstein (1980) examined are drawn from consonant errors consisting of 1369 speech errors in English (Fromkin 1980), 1057 speech errors in English (Shattuck-Hufnagel 1975), 542 speech errors in German (Meringer & Mayer 1895, Meringer 1908), and 235 speech errors in Dutch (Nooteboom 1973). The feature specifications for disambiguating the consonants involve the following: voicing, stop, place ([bi]labial, dental, alveolar, palatal, velar, glottal), and nasal. The feature fricative plus approximant is further added for classification purposes. The speech error feature system proposed by Van den Broecke & Goldstein (1980) for adult English is listed in Table 3.

Table 3. Speech error feature specifications for English consonants

	p	t	k	b	d	g	m	n	f	v	θ	ð	s	z	ʃ	l	r	w	j	h	tʃ	dʒ
Voice	-	-	-	+	+	+	+	+	-	+	-	+	-	+	-	+	+	+	+	-	-	+
Stop	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	+	+
Place	B	A	V	B	A	V	B	A	B	B	D	D	A	A	P	A	A	V	P	G	P	P
Nasal	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fric/ appr.	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	-	+	+	+	+	+	+

Van den Broecke & Goldstein (1980), who analyzed feature relationships of English slips using a multi-dimensional scaling technique, suggested the rank order of feature involvement for English given in (1).

(1) Place > Voice > Stop > Fricative + Approximants > Nasal

In general, the consonant in error is more likely to substitute for another if the two consonants differ by only one feature across all data sets. Dell (1980) and Berg (1985), from results based on their corpus, indicated that the hierarchy of feature distribution for English is different from what Van den Brocke & Goldstein (1980) had proposed, as shown in (2). Notwithstanding, they do not explain exactly what the features involved in manner are, and their hierarchies do not include nasality.

(2) Place > Manner > Voice

In summary, evidence from cross-linguistic speech-error data shows a general pattern where errors are distributed hierarchically among the phonetic features. The feature of place of articulation is the feature most often violated by speech errors in English, German, and Dutch. Two manner features and voicing are violated less often, and nasality is violated least often.

Jaeger (1992, 2004) investigated the issue as to whether there is any consonant similarity in young children's speech errors in English by use of a corpus of consonant substitution and exchange errors made by young children. Jaeger proposed a slightly different feature specification system for children's speech-error data, as shown in Table 4. The system was developed from multi-dimensional scaling procedures that capture the feature dimensions governing phonetic similarity in English. The place features involve the following: labial, dental, alveolar, rhotic, palatal, velar, and glottal.

Table 4. Consonant features and feature specifications derived from multi-dimensional scaling analysis of children's data in English

	p	t	k	b	d	g	tʃ	dʒ	f	θ	s	ʃ	h	v	ð	z	ʒ	m	n	l	r	w	j
Voice	-	-	-	+	+	+	-	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
Frication	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Place	L	A	V	L	A	V	P	P	L	D	A	P	G	L	D	A	P	L	A	A	R	L-V	P
Continuant	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nasal	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	+	+	-	-	-	-

Based on this table, Jaeger (1992) found that the various features were not equally likely to be involved in these children's speech errors. As is the case with adults, children also tend to produce consonant errors that differ by only one feature. Jaeger found that the place feature (73.5%) was the feature most often violated by speech errors in the children's production system. The two manner features were involved the next most often: continuant (33.7%), and fricative (27.1%). Voicing was involved in 20.5% of the errors, and nasality was rarely involved (14.6%). The overall hierarchy of feature involvement in errors is given in (3):

(3) Place > Continuant > Fricative > Voice > Nasal

In summary, evidence from cross-linguistic speech-error data shows a general pattern where errors are distributed hierarchically among the phonetic features. Place of articulation is the feature most often violated by speech errors in English (for both adults and children), German, and Dutch. Two manner features and voicing are violated less often, and nasality is violated least often. Faithfulness in Optimality Theory might be able to render some explanations.[2] In general phonological processes in loanword phonology (Broselow 1999, Kenstowicz 2007), faithfulness to manner features usually takes precedence over faithfulness to voicing or place features, predicting that manner features resist alternation or alteration more than voicing or place features. Similarly, in consonant adaptations within English loanwords in Mandarin, faithfulness to manner is ranked higher than faithfulness to place, suggesting that place features change more often than manner features in phonological adaptation (Miao 2005). As for the voicing feature, in perceptual

[2] I am truly grateful to one of the reviewers for pointing out phonological processes involving in loanword adaptation (Broselow 1999, Kenstowicz 2007), imperfect puns and rhymes (Zwicky & Zwicky 1986) and voicing contrasts in perceptual studies (Steriade 2008).

studies, consonants contrasting in voicing were found to be perceived more similarly than consonants contrasting in place or manner features (Steriade 2008). Based on the phonological processes and perceptual studies, one might expect to find more involvement of the voicing feature, followed by place and then by manner features in speech-error distributions. However, conflicting results might raise the question as to whether the data sources were drawn from production/articulation or from acoustics/perception since they might yield different results (Myers 2016a, 2016b). Take [t]-[s] and [t]-[p] for an example, the articulations of [t] and [s] are similar in that they both involve the same articulator in the same place, alveolar, whereas [p] requires a totally different articulator, bilabial, so the [t]-[p] contrast would be bigger than the [t]-[s] contrast. However, in acoustic studies, the spectrograms for [t] and [p] are quite similar, differing only in subtle and context-dependent slopes for their formant transitions, comparable to the spectrogram for [s]. Therefore, in perceptual studies (including loanword phonology), the [t]-[s] contrast would be bigger than the [t]-[p] contrast (p.c., James Myers). It will be interesting to see whether the pattern of violations follows such a hierarchy in Mandarin consonant errors, and whether the consonants that have different articulators or those which have different spectrograms, having the bigger contrast, are more likely to interact in errors in Mandarin.

3. Methodology and subjects

The current study is based on 292 speech errors selected from a corpus of approximately 4500 speech errors (collected by the author from native speakers of Mandarin spoken in Taiwan between 1995 and 2003). One might find the figure rather small compared with the size of corpus used in English studies. Of the 4500 speech errors, nearly 2500 (55%) errors are phonological, and of these, around 1100 (50%) errors are consonantal, which can be subdivided into single consonant errors and larger consonant units usually involving CG, GV, or VN/VG. The types of consonants involved in the errors were due to processes of substitution, deletion, addition or exchange. Only the 292 speech errors that involve single consonant substitution and exchange errors are relevant for this study. The speech-error data are derived from thousands of tape-recorded brief excerpts of natural speech. These excerpts were taken from free conversation, conference discussions, broadcasts, lectures, and from interviews with students. Standard collection procedures were followed, and all errors were analyzed and classified using the system discussed in Jaeger (2004) (for a more detailed discussion of procedures and some potential problems that might be rendered, see MacKay 1980). The subjects in this study were all native speakers of standard dialects of Mandarin spoken in Taiwan. Most of the dialects have undergone some general sound changes which are currently taking place in Taiwan, whereby the retroflex affricates [tʂ, tʂʰ, ʂ] are being lost and replaced by dental affricates [ts, tsʰ, s], and whereby the velar nasal following the high front vowel such as [iŋ] is being dropped and replaced by the dental nasal after the high front vowel such as [in]. However, certain speakers in the subject groups continue to distinguish dental from retroflex affricates. The author, thus, phonetically transcribed the actual pronunciation produced by the subjects during the error utterance.

The errors were collected from over 100 different speakers whose ages ranged from 20 to 50 years old. Note, however, that not all speakers produced errors in the data collection. For each error in the corpus, the author recorded the complete utterance, including self-corrections, and relevant contextual information. Portions were written in IPA phonetic transcription, as appropriate. Thus, the errors will be reported below in terms of the actual pronunciations produced during the error utterance. In the study, subjects ranged from monolingual to trilingual, with Mandarin as their first language and Taiwanese as their other language(s), if any. However, all the errors were collected when the speakers were conversing in Mandarin. Any errors showing a bilingual influence were not included in the data set to be examined in this paper.

In the past, most researchers collecting speech-error data relied on the native-speaker linguist's intuitions as to which categories of the native language were heard by the native listener (Fromkin 1973a). Fromkin (1973b, 1980) suggested that speech errors collected in a naturalistic setting have a cognitive validity in terms of the representation within the speakers' minds during processing. However, one might argue that obtaining the speech-error data under naturalistic conditions does not have the overriding advantage of giving insight into the psychological structures and processes actually used by native speakers in the generation of speech. Even if evidence may be derived from psychological constructs, it is not always clear at which level of analysis the speakers operate on. Cutler (1982) suggested that such a methodology is subject to some listener bias. In order to eliminate the context-effect that applies in naturalistic speech performance, Dell & Reich (1980) and Stemberger (1985) conducted a number of experiments, trying to reduce all anticipated potential distortions that might render evidential value of the errors ambiguous. Furthermore, Mowery & MacKay (1990) then suggested that in speech errors induced in the laboratory by having speakers repeat "tongue twisters" several times in succession, some phonetic differences between erroneously produced and intentionally produced consonants could be detected using electromyography. However, the majority of speech-error studies are drawn from spontaneously occurring errors, and the difference between controlled experiments and naturally occurring errors do not seem to be significant.

In Taiwan Mandarin, the best option for automatically aligning the transcript to the proper sound file is based on the forced alignment system, HTKAlignementScript_ILAS,[3] which is a Hidden Markov Model Speech Recognition Toolkit. In order to prove that native speaker perception that the segment spoken was a particular sound is a more valid psycholinguistic measure than the actual phonetic properties of the utterance, for the current study, the author subjected 15% of the instances of erroneously produced sounds in wav files and text files to phonetic transcription by the research team. It was found that there were no significant differences in analysis between the transcription phonetically marked by the research team of this study and the forced alignment toolkit. Therefore, the speech errors collected in a naturalistic setting for this study will be taken as evidence reflecting psychological constructs in the language structure, and the data to be discussed below are thus sufficiently reliable in providing matter for analyses.

Wan (1999) in an earlier study found that speech errors can occur at any stage of the speech production planning model, just as in speech errors occurring in Germanic languages. The focus in this paper is to gather speech-error evidence occurring during the phonological planning stage where underlying phonological representations are being assigned a surface phonetic form. Two types of errors that can occur during this stage are substitution and exchange. When one consonant is erroneously substituted for or exchanged with another, it is easy to estimate how many feature violations occurred between target and source segments. Questions as to whether consonants that are more phonetically similar are more likely to interact with one another will be investigated. In addition, among all the feature specifications, issues as to whether consonants display a form of featural organization will be explored.

The errors described in this study are contextual ones in which there can be a source for the error in the utterance itself. Non-contextual errors, with no source in the error utterance, will not be considered in this paper. When an error is contextual and the error occurs in a word spoken before the source of the error, this is called "anticipation"; if the error occurs in a word spoken after the source, it is a "perseveration." The errors discussed here are classified as "phonological" because non-meaningful phonological units are involved, that is, phonetic features, single consonants or vowels, clusters of segments (including consonant clusters, rhymes, etc.), whole syllables, and tones. Since most Mandarin morphemes are monosyllabic and Mandarin words are bi-syllabic, a change in one or more segments causing phonotactically permissible sequences nearly always produces actual morphemes and

[3] Professor Chiu-yu Tseng and her research team in the Phonetics Lab at Academia Sinica have been developing the forced alignment system for many decades.

thus results in another actual word in Mandarin. However, phonological errors can be distinguished from true lexical errors in that lexical errors nearly always preserve the lexical category and are usually semantically related to the intended word. A phonological relationship is less common. Phonological errors frequently violate the lexical category and have no semantic relationship to the target word. Thus, they typically produce an ungrammatical or meaningless utterance.

Throughout the paper, when each example of an error is presented, the first line will be the intended utterance (in surface phonetic transcription), the second line will provide a morpheme-by-morpheme gloss. The third line will be the error utterance, again in phonetic transcription, and the fourth a translation into English of the intended utterance. The element to the left of the arrow is the target, and the element to the right of the arrow is the error. The term 'meaningless' following the gloss of the intended utterance means either that the error utterance violates syntactic rules of Mandarin, or that the error utterance contains a semantic anomaly that renders it meaningless.

The following example illustrates the procedure followed in the classification of errors when unclear cases occurred.

(4) I: ni35 ɕi21 pu51 ɕi21-xwan55 tswɔ51 **x**wɔ21-**tʂʰ**ɤ55 → (tʂʰ→x)
you like not like sit fire-vehicle
E: ni35 ɕi21 pu51 ɕi21-xwan55 tswɔ51 **x**wɔ21-**x**ɤ55
'Do you like to take the train?' → (meaningless)

This spontaneous speech error is best analyzed as a phonological error where the consonant of the syllable [x] is perseverated and substituted for the [tʂʰ] of the following consonant leaving the vowel and tone of [ɤ55] in place. However, one might classify this case as a lexical error in which the lexical item [xɤ55] 'to drink' replaces another lexical item [tʂʰɤ55] 'car'. This interpretation is not quite correct since, in this case, the error [xɤ55] is a verb 'to drink' whereas the target [tʂʰɤ55] is a noun 'car', and the error word is not of the same lexical category as the target, has no semantic relationship to the target, and is not phonetically similar other than having the same tone. The resultant utterance is, therefore, meaningless.

In making a decision about the classification of an error, the methodology is based on the 'minimal principle' proposed by Laubstein (1987) where the simplest or most conservative analysis, the smallest segmental error unit, is always chosen. First, the majority of unambiguous phonological errors involve single consonants or vowels in all languages (i.e., Wells-Jensen 1999). Therefore, if a single segment analysis is possible, it is more likely to be correct. Second, if this principle is not adopted, the researcher could be free to choose whichever analysis he or she preferred, which could bias the analysis in favor of the researcher's preferred hypothesis. However, if there is an ambiguous error that could be classified either as a phonological or lexical error, the involvement of the smallest unit may not be the only solution. Consider the following example:

(5) I: t^{h}a55 pu35 jɑw51 k^{h}aj55 xwɔ**51**-tʂ^{h}ɤ55 → (51→21)
he not want drive goods-vehicle
E: t^{h}a55 pu35 jɑw51 k^{h}aj55 xwɔ**21**-tʂ^{h}ɤ55
fire-vehicle
'He doesn't want to drive a truck (for a living).' →
'He doesn't want to drive a train (for a living).'

In this example, the smallest unit involved in the error is the tone, the tone unit [21] replaces another tone unit [51], leaving the other segments in place. One might consider it a tone error based on the minimal principle, however, this utterance does not render a source tone unit [21] so a phonological explanation is not possible in such a case. This case can be best described as a lexical error since [xwɔ51-tʂ^{h}ɤ55] 'truck' and [xwɔ21-tʂ^{h}ɤ55] 'train' preserve the same lexical category, and they have identical segments except that the tones in the first syllable are different. It is often found in English speech errors that two lexical items are semantically related when they are substituted one for the other, and in many cases, they are also phonologically related. In English there is a class of substitutions known as malapropisms where there is only a phonological relationship, however, malapropisms are rare in Mandarin, where nearly every lexical substitution error shows a semantic relationship (Wan 2016).

4. Findings and results

Defining whether one segment is phonetically similar to another is done by looking at how many phonetic features the two segments share. Van den Broecke & Goldstein (1980) compared a number of feature systems and proposed a new one that incorporates evidence from speech errors in English and German. Jaeger (1992, 2004) also adopted a similar feature system. Based on these cross-linguistic studies, a similar feature system for Mandarin has been developed, as shown in Table 5. All the contextual single-consonant substitution and exchange errors found in the speech error databank will be provided to see whether they display phonetic similarity between target and source segments, to test whether a hierarchy and rank order exist in consonantal features in Mandarin, and to examine whether the featural organization is similar to or different from the rank order found in Van den Broecke & Goldstein (1980) and Jaeger (1992, 2004).

Table 5. Speech error specifications for Mandarin consonants

	p	pʰ	t	tʰ	k	kʰ	ts	tsʰ	tʂ	tʂʰ	tɕ	tɕʰ	f	ɕ	x	s	ʂ	ʐ	m	n	ŋ	l	ɥ	j	w
P	L	L	D	D	V	V	D	D	R	R	P	P	L	P	V	D	R	R	L	D	V	D	L-P	P	L-V
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-
V	O	A	O	A	O	A	O	A	O	A	O	A	O	O	O	O	O	V	V	V	V	V	V	V	V
C	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+
F	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-

In Table 5, there are five parameters for Mandarin in the feature system. They are *place of articulation, nasality, voice onset time, continuancy,* and *frication*:

(a) *Place of articulation*: This non-binary feature is divided into seven places: labial (L), dental (D), retroflex (R), labio-palatal (L-P), palatal (P), labio-velar (L-V), and velar (V).

(b) *Nasality*: The three nasals—labial, dental, and velar—have a positive value in regard to this feature.

(c) *Voice onset time*: This dimension is divided into voiceless aspirated (A), voiceless unaspirated (O), and voiced (V). In addition, there is a two-way contrast in Mandarin stops and affricates for aspiration, but fricatives and sonorants are [+voice] non-contrastive.

(d) *Continuancy*: All sonorants and fricatives are labeled [+continuant]. Affricates are distinguished from fricatives by being [-continuant]. Stops, of course, are [-continuant].

(e) *Frication*: All fricatives and affricates are labeled as [+frication], and all others are [-frication].

The featural relationships between every pair of consonant phones in Mandarin were analyzed in order to calculate a figure for feature differences to be expected among each feature dimension. The tabulation is shown in Table 6, which lists all possible feature differences, from one to five, among consonant pairs in Mandarin.[4]

[4] This chart lists the interaction among phones, since phonemes (i.e., palatals and other allophones) are not the focus of this study. Segments that are allophones of the same phoneme will not substitute for

Table 6. Possible feature differences in Mandarin consonants

	p	p^h	t	t^h	k	k^h	ts	ts^h	tʂ	tʂ^h	tɕ	tɕ^h	f	ɕ	x	s	ʂ	ʐ	m	n	ŋ	l	ɥ	j	w
p		1	1	2	1	2	2	3	2	3	2	3	2	3	3	3	3	4	3	4	0	3	3	3	3
p^h	1		2	1	2	1	3	2	3	2	3	2	3	4	4	4	4	4	3	4	0	3	3	3	3
t	1	2		1	1	2	1	2	2	3	2	3	3	3	3	2	3	4	4	3	0	2	3	3	3
t^h	2	1	1		2	1	2	1	3	2	3	2	4	4	4	3	4	4	4	3	0	2	3	3	3
k	1	2	1	2		1	2	3	2	3	2	3	3	3	2	3	3	4	4	4	0	3	3	3	3
k^h	2	1	2	1	1		3	2	3	2	3	2	4	4	3	4	4	4	4	4	0	3	3	3	3
ts	2	3	1	2	2	3		1	1	2	1	2	2	2	2	1	2	3	5	4	0	3	4	4	4
ts^h	3	2	2	1	3	2	1		2	1	2	1	3	3	3	2	3	3	5	4	0	3	4	4	4
tʂ	2	3	2	3	2	3	1	2		1	1	2	2	2	2	2	1	2	5	5	0	4	4	4	4
tʂ^h	3	2	3	2	3	2	2	1	1		2	1	3	3	3	3	2	2	5	5	0	4	4	4	4
tɕ	2	3	2	3	2	3	1	2	1	2		1	2	1	2	2	2	3	5	5	0	4	4	3	4
tɕ^h	3	2	3	2	3	2	2	1	2	1	1		3	2	3	3	3	3	5	5	0	4	4	3	4
f	2	3	3	4	3	4	2	3	2	3	2	3		1	1	1	1	2	3	4	0	3	3	3	3
ɕ	3	4	3	4	3	4	2	3	2	3	1	2	1		1	1	1	2	4	4	0	3	3	2	3
x	3	4	3	4	2	3	2	3	2	3	2	3	1	1		1	1	2	4	4	0	3	3	3	3
s	3	4	2	3	3	4	1	2	2	3	2	3	1	1	1		1	2	4	3	0	2	3	3	3
ʂ	3	4	3	4	3	4	2	3	1	2	2	3	1	1	1	1		1	4	4	0	3	3	3	3
ʐ	4	4	4	4	4	4	3	3	2	2	3	3	2	2	2	2	1		3	3	0	2	2	2	2
m	3	3	4	4	4	4	5	5	5	5	5	5	3	4	4	4	4	3		1	0	2	2	2	2
n	4	4	3	3	4	4	4	4	5	5	5	5	4	4	4	3	4	3	1		1	1	2	2	2
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	2	2
l	3	3	2	2	3	3	3	3	4	4	4	4	3	3	3	2	3	2	2	1	0		1	1	1
ɥ	3	3	3	3	3	3	4	4	4	4	4	4	3	3	3	3	3	2	2	2	0	1		1	1
j	3	3	3	3	3	3	4	4	4	4	3	3	3	2	3	3	3	2	2	2	2	1	1		1
w	3	3	3	3	3	3	4	4	4	4	4	4	3	3	3	3	3	2	2	2	2	1	1	1	

This table lists all possibly expected feature differences in Mandarin. The numbers in the columns indicate the number of feature differences in Mandarin. For example, the consonants [p] and [p^h] are different by one feature, which is aspiration. Table 7 shows the number of pairs of consonant phones in Mandarin which differ by one to five features.

each other in errors. Also, the zeros in the column under [.·˙] indicate the fact that [.·˙] occurs only in the coda position and so could be substituted only by [n]. All other substitutions are possible.

Table 7. Number of pairs of consonant phones in Mandarin which differ by 1 to 5 features

Feature(s)	Number	Percentage
3	99	35
2	71	26
4	56	20
1	43	15
5	10	4
Total	279	100

Table 7 shows that three-feature differences (N=99, 35%) among consonant pairs are the most common, two- or four-feature differences (N=71, 26%; N=56, 20%) are less common, one-feature differences (N=43, 15%) are much less common, and pairs that differ in value for all five features are the least common (N=10, 4%). Table 8 further shows the number of pairs of consonant phones in Mandarin that differ by the type of features involved.

Table 8. Number of pairs of consonant phones in Mandarin that differ by the feature combination involved

Number of feature(s)	Feature(s)	Number	Percentage
3	PVC	40	35
3	PVF	32	
3	PCF	12	
3	VCF	7	
3	NVC	4	
3	NVF	2	
3	PNF	2	
2	PF	20	26
2	PV	16	
2	PC	12	
2	PN	9	
2	VC	7	
2	VF	4	
2	CF	3	
4	PVCF	38	20
4	PNVC	8	
4	PNVF	8	
4	NVCF	2	

Number of feature(s)	Feature(s)	Number	Percentage
1	P	30	15
1	V	7	
1	C	3	
1	F	2	
1	N	1	
5	PNVCF	10	4
Total		279	

The data presented in Table 8 further shows that three-feature differences among consonant pairs involving the combination of [place], [VOT], and [continuancy] features are the most common in consonant phones in Mandarin. Four-feature differences among consonant pairs involving the combination of [place], [VOT], [continuancy], and [frication] features are the next most common. Three-feature differences involving [place], [VOT], and [frication] features, and one-feature differences involving [place] features only are also common. A one-feature difference involving nasality only among consonant pairs is the least common in consonant phones in Mandarin. The following table, Table 9, further shows the number of pairs of consonant phones in Mandarin which differ by each of the features: [place], [VOT], [frication], [continuancy], and [nasality].

Table 9. Number of pairs of consonant phones in Mandarin differing according to specific features

Feature(s)	Number	Percentage
Place	237	31
VOT	185	25
Continuancy	146	19
Frication	142	19
Nasality	46	6
Total	756	100

This table further shows that the feature differences are distributed unevenly in consonant phones in Mandarin taking the type of features (including combination of feature types) into consideration. In the five-feature parameter, the feature [place] is the feature that differs in the largest number of pairs whereas the feature [nasality] differs in the fewest number of pairs since all but two segments are [-nasal].

Since feature violations from one to five are all possible in Mandarin consonant phones, one might expect to find one- to five-feature difference(s) involved in speech errors. In errors, if the source-target pairing is a violation of one feature difference, such a violation could occur, (for example, in the interaction of [p]-[t] where the difference is found in place of articulation, [p] being labial and [t] being dental). If the source-target pairing violates two feature differences, such a violation could occur, (for example, in the interaction of [p]-[tʰ] where differences are found in place of articulation and in voice onset time, [p] being labial and [-aspirated] and [tʰ] being dental and [+aspirated]). If the source-target pairing violates three feature differences, such a violation could occur, (for example, in the interaction of [p]-[tsʰ] where differences are found in place of articulation, voice onset time, and frication, [p] being labial and [-aspirated, -fricative] and [tsʰ] being dental and [+aspirated, +fricative]. If the source-target pairing is a violation of four feature differences, such a violation could occur (for example, in the interaction of [p]-[ʐ] where differences are found in place of articulation, voice onset time, continuancy, and frication, [p] being labial and [-voiced, -continuant, -fricative] and [ʐ] being retroflexed and [+voiced, +continuant, +fricative]). If the source-target pairing is a violation of five feature differences, such a violation could occur, (for example, in the interaction of [ts]-[m], which differ on all five parameters in the feature system, including place of articulation, nasality, voice onset time, continuancy, and frication. In this case, [ts] is dental and [-voiced, -nasal, -continuant, -fricative] and [m] is labial and [+voiced, +nasal, +continuant, +fricative]. Since feature violations one through five are all possible among consonant pairs in Mandarin, Table 10 below shows how source and target consonants interact in terms of the feature violations in speech errors in Mandarin.

Table 10 presents the actual number of Mandarin speech errors in which the two consonants involved in the error differed in one to five features. Errors included in this table involve only syllable-initial consonant substitution errors (perseveration, anticipation, anticipation/perseveration, exchange), and syllable-final single consonant substitution errors (perseveration, anticipation, anticipation/perseveration, exchange).

Seventy-nine cases which involve [n]-[ŋ] interactions in a syllable-final position are the most common, and the most frequent error in syllable-initial position is [t]-[k] interactions. Table 10 shows the actual number of errors in which each number of features was violated in Mandarin speech errors. All consonant substitution and exchange errors were tabulated without indicating, in the case of the substitutions, which was the target and which was the error in order to have the largest possible number of data points.

Table 10. Grid indicating the number of times each pair of segments was either involved in substitutions with each other or exchanged for each other, target vs. source/error not indicated[5]

	p	pʰ	t	tʰ	k	kʰ	ts	tsʰ	tʂ	tʂʰ	tɕ	tɕʰ	f	ɕ	x	s	ʂ	ʐ	m	n	ŋ	l	ɥ	j	w
p		1	7	1	2	0	3	0	0	0	1	0	7	0	0	0	0	0	3	0	0	3	0	0	1
pʰ			2	2	0	1	0	0	0	1	0	0	2	0	1	0	0	0	1	0	0	0	0	0	1
t				4	12	0	0	0	3	1	3	0	0	0	0	1	0	0	1	1	0	2	0	0	0
tʰ					0	4	0	1	1	3	1	0	0	1	2	2	0	0	0	1	0	3	0	0	0
k						3	3	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
kʰ							0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ts								0	0	0	1	0	0	0	1	4	3	0	0	0	0	0	0	0	0
tsʰ									0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
tʂ										2	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0
tʂʰ											0	0	0	1	0	0	4	0	0	0	0	0	0	0	0
tɕ												2	0	7	0	0	0	0	0	0	0	0	0	0	0
tɕʰ													0	4	0	0	0	0	0	0	0	0	0	0	0
f														0	9	0	1	0	0	0	0	0	0	0	0
ɕ															0	1	0	0	0	1	0	0	0	0	0
x																2	1	0	0	0	0	0	0	0	0
s																	0	0	0	0	0	0	0	0	0
ʂ																		1	0	0	0	0	0	0	0
ʐ																			0	2	0	2	0	0	1
m																				2	1	3	0	0	4
n																					79	7	0	10	4
ŋ																						0	0	0	11
l																							0	0	0
ɥ																								10	1
j																									6
w																									

[5] Note that in the tabulation, zero refers to positive information, indicating that these are consonants that are never confused with each other.

Table 11. Percentage of consonant errors with number of features violated

Feature(s)	Number	Percentage
1	179	61
2	83	29
3	24	8
4	6	2
5	0	0
Total	292	100

Table 11 shows that feature violations among consonant pairs in errors are not distributed evenly. The mean number of substitution errors involving a change of one feature is 179, of two features, 83, of three features, 14, and of four features, 6. Therefore, occurrences where only one feature is violated between the source and target pairs are by far the most common (61%), two feature violations are less common (29%), three feature violations are much less common (8%), four feature violations (2%) are the least common, and no errors violate all five features. There is a monotonic decrease as the number of feature differences increases. This pattern cannot be random since, from the results of the possibly expected feature differences presented in Table 7, it can be predicted that only 15% of the consonant pairs in Mandarin differ by only one feature, but 61% of the cases in Table 11 have such a property. This finding supports the hypothesis that consonants that are more phonetically similar are more likely to interact in errors. This property has been found in every language for which data are available (Mackay 1973, Nooteboom 1973, Berg 1987, Jaeger 1992).

The following are some examples that show all possible feature differences from one to four when source and target consonants both occur syllable-initially or syllable-finally.

(6) I: **$\underline{t^h}$**ow35 **$\underline{t}$**a51 → (t→t^h)
head big
E: **$\underline{t^h}$**ow35 **$\underline{t^h}$**a51
'(I am having a big) trouble.' → (meaningless)

Example (6) shows a case in which the source consonant [t^h] is perseverated and substitutes for the target consonant [t]. The target-source pairing shows a one-feature difference, and the pair is different by the feature of voice onset time where [t^h] is aspirated and voiceless and [t] is unaspirated and voiceless.

(7) I: **f**a55-pjɑw21 **p**ej51-lɤ i51-tʰjɛn55 → (p→f)
present recite-PERF one-day
E: **f**a55-pjɑw21 **f**ej51-lɤ i51-tʰjɛn55
'(For the) presentation (he) recited (the draft) for a day.' → (meaningless)

Example (7) shows a case in which the source consonant [f] is perseverated and substitutes for the target consonant [p]. The target-source pairing shows a two-feature difference, and the differences are found in the features of continuancy and of frication where [p] is [-continuant] and [-fricative] and [f] is [+continuant] and [+fricative].

(8) I: **p**a21-**p**a35 **m**a51 ma55 → (m→p)
papa blame mama
E: **p**a21-**p**a35 **p**a51 ma55
'Papa blamed mama.' → (meaningless)

Example (8) shows a case in which the source consonant [p] is perseverated and replaces the target consonant [m]. The target-source pairing shows a three-feature difference, and the pair differ by the features of nasality, of voice onset time, and of continuancy where [m] is [+nasal, +voiced, +continuant] and [p] is [-nasal, voiced, -continuant].

(9) I: pu51 **ɕ**jɑŋ21 **n**jɛn51-ʂu55 → (n→ɕ)
not want read-book
E: pu51 **ɕ**jɑŋ21 **ɕ**jɛn51-ʂu55
'(I) don't want to study.' → (meaningless)

Example (9) shows a case in which the source consonant [ɕ] is perseverated and substitutes for the target consonant [n]. The target-source pairing shows a four-feature violation, the violations being made in place of articulation, nasality, voice onset time, and frication where [n] is dental and [+nasal, +voiced, -fricative] and [ɕ] is palatal and [-nasal, -voiced, +fricative].

(10) I: tʰaj51 wa**n**35 tʂɑw21 fɑ**ŋ**35-tsɨ → (n→ŋ)
too late find house
E: tʰaj51 wɑ**ŋ**35 tʂɑw21 fɑ**ŋ**35-tsɨ
'It is late to look for a house.' → (meaningless)

Example (10) shows a case in which the source final consonant [ŋ] is anticipated and substitutes for the target final consonant [n]. The target-source pairing shows a one-feature violation, and the pair is violated by the feature of place of articulation where [ŋ] is velar and [n] is dental.

(11) I: kɑ**<u>ŋ</u>**35-kʰo**<u>w</u>**21 → (w→ŋ)
port-mouth
E: kɑ**<u>ŋ</u>**35-kʰo**<u>ŋ</u>**21
'the port' → (meaningless)

Example (11) shows a case in which the source final consonant [ŋ] is perseverated and substitutes for the target consonant [w]. The target-source pairing shows a two-feature difference, the differences being made in place of articulation and nasality where [ŋ] is velar and [+nasal] and [w] is labial-velar and [-nasal].

Table 12 shows the pairs of source-target consonant errors by the type of feature involved.

Table 12. Percentage of consonant errors by combination of the type of features involved

Number of feature(s)	Feature(s)	Number	Percentage
1	P	143	61
1	C	14	
1	V	13	
1	N	7	
1	F	2	
2	PF	20	29
2	CF	12	
2	CV	11	
2	PN	32	
2	PV	4	
2	PC	4	
3	PCV	8	8
3	NVC	6	
3	VCF	5	
3	PVF	3	
3	PNF	2	
4	PVCF	4	2
4	PNVC	1	
4	PNVF	1	
Total		292	100

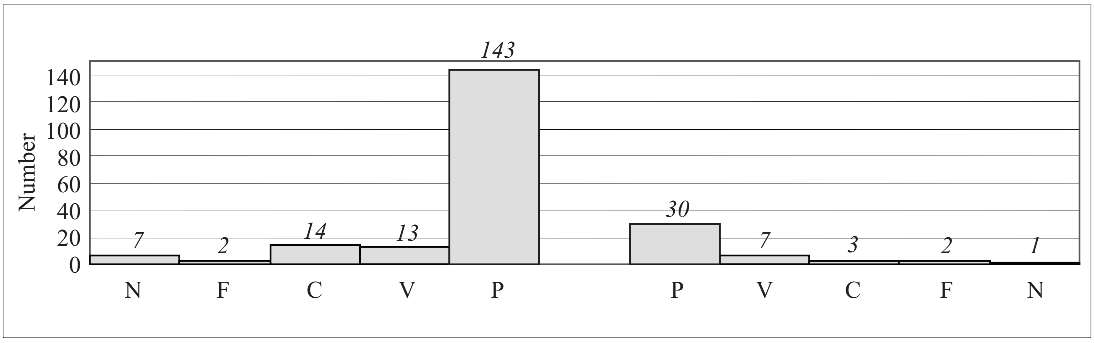

Figure 1. Number of consonant errors (left) and consonant phones (right) in Mandarin which differ by the type of features involved

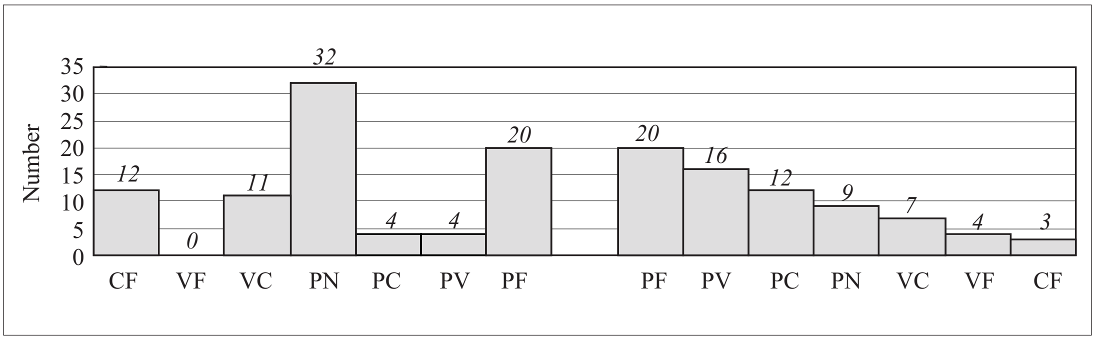

Figure 2. Number of consonant errors (left) and consonant phones (right) in Mandarin which differ by the type of features involved

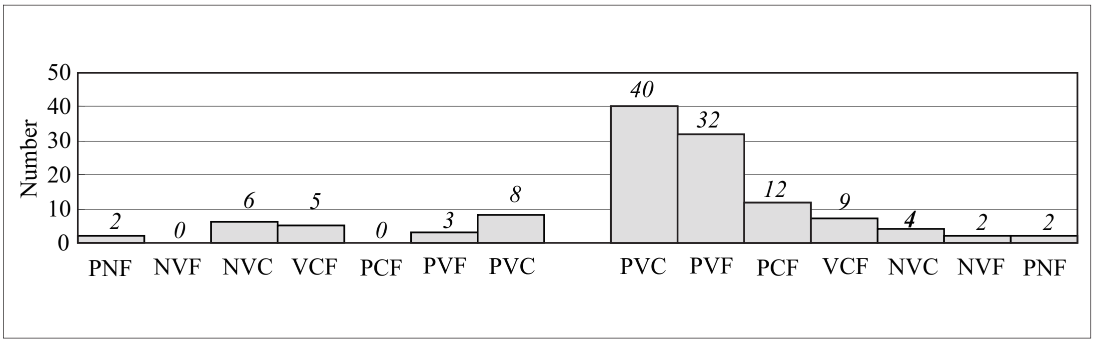

Figure 3. Number of consonant errors (left) and consonant phones (right) in Mandarin which differ by the type of features involved

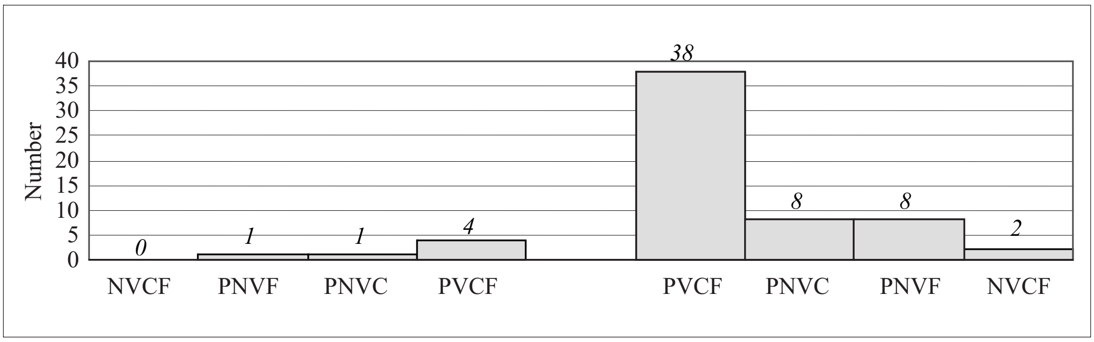

Figure 4. Number of consonant errors (left) and consonant phones (right) in Mandarin which differ by the type of features involved

A chi-square test was done to compare the distribution of consonant errors (observed) vs. consonant phones (expected) by number of features and type of features (including combination of feature types) in Mandarin. The results yield a marginally significant difference between the observed and expected data (χ^2 (4) = 180.102, p < .01), suggesting that the number and the type of feature differences in consonant phones do not entirely provide a basis for a good prediction of the rate of error distribution in Mandarin. A chi-square test further showed that the proportion of feature-difference violations in consonant pairs yields a marginally significant difference (χ^2 (3) = 249.671, p < .01). It is evident in these figures from the observed data that the largest number of errors involved consonant pairs that differ by only one feature, followed by consonant pairs that differ by two features. This finding is very different from the expected data in that the majority of consonant pairs were expected to differ by two- or three-feature violations. In summary, in all of the whole segments involving contextual single consonant substitution and exchange errors in Mandarin, the target and source segments display a phonetic similarity.

Table 13 shows the number of pairs of consonant errors in Mandarin which differ by each of the features: [place], [VOT], [frication], [continuancy], and [nasality]. Note that the percentages add up to more than 100%, since many errors involve more than one feature.

Table 13. Percentages of consonant errors with specific features violated

Features	Total
Place	222 (50%)
Continuancy	65 (15%)
VOT	56 (13%)
Frication	49 (11%)
Nasality	49 (11%)
Total features	441

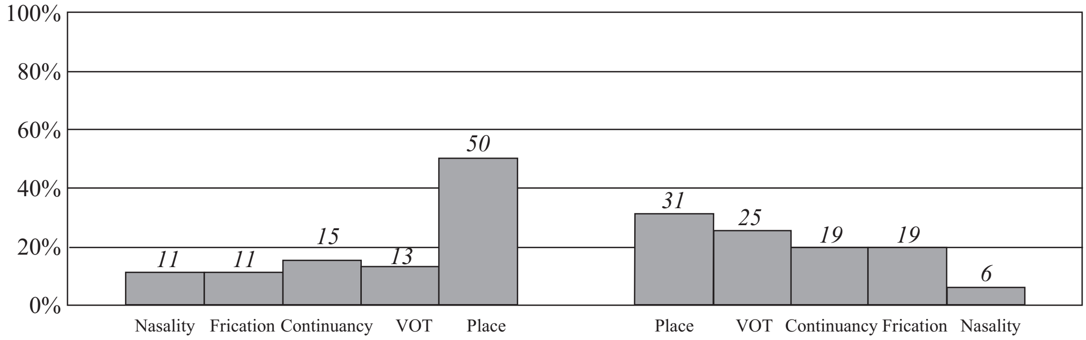

Figure 5. Percentages of consonant errors (left) and consonant phones (right) in Mandarin Chinese that differ by the type of feature involved

A chi-square test was done to compare the type of feature violations occurring in consonant pairs in the observed vs. expected data. The results again showed a marginally significant difference (χ^2 (4) = 255.678, $p < .01$). The data in this table show that errors are not distributed evenly among the phonetic features, but rather are distributed hierarchically. In addition, the feature differences in consonant phones in Mandarin clearly do not make a prediction of error distribution in Mandarin speech. The feature of place of articulation is by far the feature most often violated by speech errors, with the manner features of continuancy and voicing being violated less often, the other manner features, frication and nasality, being violated least often. This finding is different from that which has been found in cross-linguistic studies because there seem to be slightly higher rates for the features of place of articulation and of nasality in Mandarin.

Since there are restricted phonotactic constraints in Mandarin, the possibilities of error interactions in final coda positions can only be limited to specific patterns including a glide substituting for another glide, a nasal substituting for another nasal, and a glide substituting for a nasal and vice versa because only glides and nasals are allowed to occur in word-final positions in Mandarin. It has long been noted that error generation honors the syllabic position so a syllable-initial consonant interacts with another syllable-initial consonant, and a syllable-final consonant interacts with another syllable-final consonant. Therefore, the tendency of one segment to substitute for another segment would be related to the syllabic position because there are more opportunities for initial consonants to interact with one another than coda consonants, and thus the type of consonant errors will not be equally frequent in syllable-initial positions versus those in syllable-final positions. The following table further lists the consonant substitution/exchange errors in terms of their syllabic positions.

Table 14. Consonant errors with specific features violated by syllable position, given as a percentage

Features	Initial position	Final position	Total # and %
	# and % of errors	# and % of errors	
Place	113 (37%)	109 (81%)	222 (50%)
Continuancy	65 (21%)	n.a.	65 (15%)
VOT	56 (18%)	n.a.	56 (13%)
Frication	49 (16%)	n.a.	49 (11%)
Nasality	24 (8%)	25 (19%)	49 (11%)
Total features	307 (70%)	134 (30%)	441 (100%)

It is clearly seen that syllable-initial consonants interact with one another more frequently than syllable-final consonants. Around 70% of consonant substitution/exchange errors occur with word initial onsets. This property is consistent with the finding in cross-linguistic studies in which initial consonants are more likely to slip than noninitial ones (e.g., Dell & Juliano 1996). The feature most commonly involved in the syllable-initial position is place of articulation (37%), followed by continuancy, VOT, and frication, while nasality is rare. The feature most frequently involved in the syllable-final position is also place of articulation (81%) and again nasality is very rare (19%). This finding is not surprising since all other consonants including glides can occur syllable-initially except for the consonant [ŋ] that cannot occur in the syllable-initial position as an onset. Except for those cases in which the nasal consonants [n,ŋ] and the glides [j,w] are allowed to occur syllable-finally, all other consonants are prohibited. Therefore, there are only one to two feature violations possible in the syllable-final position. They violate either the [place] feature or the [place] feature and nasality. Evidence from error distribution in syllable-final position shows that target and source segments are more likely to violate the [place] feature. Examples of errors occurring in the syllable-final position have been shown in (10) and (11). Thus, if only the substitution/exchange errors in the syllable-initial position are taken into consideration due to the fact that fewer consonants can occur syllable-finally, the hierarchy of feature differences in consonant pairs which interact in speech errors in Mandarin involve the five features in different proportions, as given in (12):

(12) Place > Continunacy > VOT > Frication > Nasality

This hierarchical order is generally in agreement with the finding in a number of languages for which data are available. In summary, cross-linguistic studies from both adults' and children's errors have shown that place of articulation is the feature most likely to be violated (e.g., Nooteboom 1973, Van den Brocke & Goldstein 1980, Stemberger 1985, Berg 1985). However, similarity is not evenly distributed among the phonological parameters. For example, Dell (1980) and Berg (1985) found that manner of articulation was less often involved in speech errors and voice least often, whereas Van den Brocke & Goldstein (1980) and Jaeger (1992, 2004) found that voice was violated more often than manner (nasality). The Mandarin result is in fact very similar to what Van den Brocke & Goldstein and Jaeger have found, suggesting that a Place > Manner > Nasality hierarchy may have some cross-linguistic validity in speech production and planning.

Therefore, these errors described in this present study convincingly show that consonant features have a psychological status during speech production planning. In consonantal errors, errors in which only one feature is violated are by far the most common (61%), and no error violates all five features, suggesting that consonants which are phonetically more similar are more likely to interact in errors.

5. Discussion and conclusion

This paper explored feature distributions and hierarchies in terms of speech errors in Mandarin. Two main issues have been discussed, phonetic similarities in target-source consonants and the hierarchy or rank order of feature distributions. In addition to the number of times whole segments involve contextual single-consonant substitution and exchange errors, frequency effects might also render some explanation. Frequency types involving the expected inventory frequency and occurrence frequency within the spoken corpus (the Spoken Mandarin Research and Resource drawn from Academia Sinica or the NCCU corpus of spoken Chinese, provided at National Chengchi University) could be taken into consideration.

The first frequency type that is relevant to the current study is the expected inventory frequency in Mandarin. One might be able to find the number of feature differences as well as the number of feature distributions in any given language. This study has provided evidence for utilizing a feature system that was developed from Van den Brocke & Goldstein (1980) and Jaeger (1992, 2004) to discuss whether there is a phonetic similarity between target and source segments. Based on the possible feature differences to be expected in Mandarin, the results show that the number of pairs of consonant phones in Mandarin can differ by one to five features. Three-feature differences among consonant pairs are the most common in the expected case, and the rank order is 3 > 2 > 4 > 1 > 5.

In addition to the expected inventory frequency in Mandarin, the other source used in looking at occurrence frequency is drawn from a larger spoken corpus, for instance, the occurrence of consonants in Mandarin from a representative spoken corpus, the Spoken Mandarin Research and Resource at Academia Sinica, where one can find the most frequently used lexicon.[6] In such a spoken corpus, a frequency count of occurrence shows that of the 12,695 most frequently used words, 2,497 (20%) words consist of monosyllables, and 10,198 words consist of disyllables (80%), which can be further categorized into three groups based on the initial consonants in the first and second syllables: in 813 (8%) words, the two syllables begin with the identical initials, in 675 (7%) words, one syllable begins with a consonant and the other begins with a vowel, and in 8,710 (85%) words, the two syllables begin with different consonants. Moreover, in the co-occurrence of different initial consonants, it is found that of the 8,710 words, the initial consonants in the first and second syllables of 2,885 words (33.1%) share three feature differences; 2,572 words (29.5%) share two feature differences; 1,729 words (19.9%) share only one feature difference; 1,304 words (15%) share four feature differences; and 220 (2.5%) share five feature differences. The feature differences in the initial consonants for the disyllables have the following rank order in the spoken corpus: 3 > 2 > 1 > 4 > 5. The rank order in the spoken corpus at Academia Sinica and in the expected case in Mandarin show a similar hierarchy, and both show a three-feature difference tendency. However, it was found that feature violations among consonant pairs in Mandarin speech errors are not distributed evenly. In addition, the number and the type of feature differences in consonants phones and in the spoken corpus do not make a good prediction of the rate of error distribution in Mandarin. It is clear that such distributions cannot be entirely explained with reference to the possibility of the number of feature violations. Not all single segment types are equally likely to be involved in speech errors.

The expected possible feature differences in consonant pairs could be predicted to generate the feature differences that interacted in the errors in different proportions

[6] I am grateful to one of the reviewers for suggesting the co-occurrence of the disyllables in the Mandarin spoken corpus, which might better prove that a certain feature type would have a special status in terms of the consonant hierarchy in the Mandarin lexicon. However, it is well noted that in the contextual errors in any speech-error corpora, for which relevant data have been reported so far (e.g., Fromkin 1973a, 1980, 1998, Garrett 1975, 1976), the target-source units causing the error substitutions or other interactions nearly always cross syllable boundaries, within-syllable error interactions are less common. In the current study, the target-source interactions have almost twice as many across syllables (N=191, 65%) as within syllables (N=101, 35%). Furthermore, Garrett (1975, 1976) found that 85 percent of target-source interactions involve elements within a single clause, and Fromkin (1973a, 1980 1998) found 79 percent of such interactions involve words in the same clause implying that speech is planned in clausal units. However, another 15 percent of such interactions in Garrett's corpus and 21 percent of those in Fromkin's corpus involve elements from more than one clause suggesting that speakers plan far ahead and construct syntactic structures in advance, prior to producing speech.

and types. Therefore, in both the expected inventory frequency and the spoken corpus at Academia Sinica, the majority of pairs of consonant phones show a three-feature difference tendency. From this, it is possible to predict that a large number of errors with three-feature differences would be generated in the error distribution in Mandarin. However, it was found that the largest number of speech errors involves consonant pairs that differ by only one feature, followed by consonant pairs that differ by two features. There is a monotonic decrease as the number of feature differences increases. The data show that errors in which only one feature is violated are the most common, supporting the hypothesis that consonants that are more phonetically similar are more likely to interact in errors. This property clearly shows that consonant similarity does influence the generation of speech errors so most errors involve phonetically similar pairs of consonants. Moreover, this study simply confirms the cross-linguistic findings found in English, German and many other languages (e.g., Dell 1980, Van den Broecke & Goldstein 1980, Berg 1985, Levitt & Healy 1985, Stemberger 1989, Jaeger 1992, 2004). It also confirms the findings that theoretically motivated linguistic features usually do not provide empirically adequate measures of similarities between phonemes in perceptual, production and psycholinguistic studies (e.g., Miller & Nicely 1955, Wicklegren 1965, 1966, Luce 1986, Goldinger, Luce & Pisoni. 1989, Bailey & Hahn 2004), and a subset of phonetic features in the feature system (Van den Brocke & Goldstein 1980) can make a simple prediction of the error patterns in Mandarin during on-line speech production planning.

When taking feature type into consideration in the expected inventory frequency, of the five feature parameters, [place] is the feature which differs in the largest number of pairs whereas [nasality] differs in the fewest number of pairs, and the rank order is predicted to be the following: Place > VOT > Continuancy = Fricative > Nasality. As for occurrence frequency in the spoken corpora, the NCCU corpus of spoken Chinese offers a general view in that each consonant (including glides) is counted as the number of times it is produced in the corpus. Of the 130,324 tokens, the dental stop [t] has the highest frequency rate (N=13,944 10.7%), followed by the retroflex fricative [ʂ] (N=13,223, 10.1%) and the palatal affricate [tɕ] (N=11,290, 8.7%). The consonants with the lowest frequency rate are the dental fricative [s] (N=1,635, 1.3%), the aspirated dental affricate [ts^h] (N=1,256, 0.96%), and the aspirated labial stop [p^h] (N=1,175, 0.90%). The most frequent consonant feature types are divided by place of articulation, manner of articulation, and VOT, and the following rank order is found: (1) Place: Dental (27.59%) > Palatal (22.71%) > Retroflex (20.08%) > Velar (16.85%) > Labial (12.77%), (2) Manner: Oral stops (35.89%) > Affricates (27.21%) > Fricatives (22.82%) > Nasal stops (9.16%) > Laterals (3.05%) > Glides (1.87%), (3) VOT: Unaspirated consonants (71.24%) >

Voiced consonants (19.02%) > Aspirated consonants (9.74%). In this spoken corpus, it is interesting to see that dentals are the most frequently produced place of articulation, and oral stops are the most common manner of articulation, with unaspirated consonants far outnumbering the others. In the spoken Mandarin Research and Resource at Academia Sinica, for those most frequently used disyllabic words involving a one-feature difference of the possible five-feature parameters (N=1,729), the co-occurrence in the initial consonants of the two syllables shows that [place] (N=956, 55.29%) is the most preferred type, [nasality] (N=295, 17.6%) is the second most preferred type, followed by [VOT] (N=281, 16.25%) and [continuancy] (N=146, 8.44 %), with [fricative] (N=51, 1.96%) being the least preferred type. In the expected inventory frequency count and in the disyllabic words drawn from the spoken corpus at Academia Sinica, the feature [place] seems to be the most frequently produced feature type although the two corpora yield a different rank order for [nasality]. Moreover, in the NCCU corpus of spoken Chinese, dentals are found to be the most common type. In the current study, in addition to the substitution/exchange errors occurring in the final coda position, Mandarin speakers are more likely to produce errors which involve a change in value for the [place] feature, and fewer errors involving the [continuancy], [VOT], and [fricative] features, and relatively fewer errors involving the [nasality] feature. The pattern of involvement is very much determined by the pattern of a possibly expected percentage, which is considered the inventory frequency. It is not a surprising fact since the feature [place] is the feature which differs in the largest number of pairs whereas the feature [nasality] differs in the fewest number of pairs for the five feature parameters. Evidence from the error distribution of speech errors, in the expected inventory frequency count, and in the Spoken Mandarin Research and Resource at Academia Sinica suggest that the feature [place] is more underrepresented than the other sets in the five-feature parameters.

In the current study, there is no doubt that the [place] feature is the one that is violated the most often in errors because there are in total seven feature values along this dimension comprising labial, dental, retroflex, labial-palatal, palatal, labial-velar, and velar. Any consonants that have been randomly selected have a high possibility of differing in regard to this feature. At the same time, the [nasality] feature is the one that is violated the least often because when [m] and [n] interact with one another they are [-nasal], and in the Mandarin error corpus, nasals are more likely to interact with one another than any other consonants (N=79). As for the features [continuancy], [VOT], and [frication], occurrences of the feature [continuancy] slightly outnumber that of the feature [VOT], which slightly outnumber that of the feature [frication]. Among the consonant pairs, about half of the consonants have [+continuant] or [+fricative] values and the other half have [-continuant] or [-fricative] values and so these features would be involved frequently by chance. Also, since there are three feature values along the [VOT] dimension including voiceless aspirated, voiceless unaspirated, and voiced, it is likely that consonant pairs will differ on this feature. In summary, the patterns found in feature errors can be explained with reference to the possibility of feature violation. Thus, the frequency factor is part of the explanation. Since in possibly expected frequency, 'place' is a multi-dimensional feature, 31% of consonant pairs in Mandarin differ by place whereas only 24% differ by voice, 19% by the two manner features (continuancy, frication), and 6% by nasality. The pattern of violations follows this hierarchy (place:37% > continuancy:21% > VOT:18% > frication:16% > nasality:8%). This suggests that feature systems are in fact organized hierarchically, and that this organization most likely accounts for the Mandarin findings and possibly also for cross-linguistic trends.

Many theories have claimed to be able to account for phonological cognition in production, perception and acquisition of phonological structures and patterns. Faithfulness in Optimality Theory might play a central role in explaining the error patterns in speech-error data. In loanword adaptation (Broselow 1999, Miao 2005, Kenstowicz 2007), faithfulness to manner is ranked higher than faithfulness to place, suggesting that place features are more likely to change in phonological adaptation. Similarly, in speech errors, consonants that differ in place are more likely to interact with each other, suggesting that place features are more likely to change in error patterns. Therefore, a production study such as one on speech errors also shows a similar pattern in loanword phonology. Regarding place and manner features, recall that Myers (2016a) presented a different solution between production/articulation and perception/acoustics. Speech-error data do not show any different results from a perceptual study, such as loanword phonology. This suggests that those consonants formed with different articulators, having the bigger contrast, are more likely to interact in errors in Mandarin. However, as for voicing features, speech errors in Mandarin seem to disagree with the findings in perceptual analysis since voicing features tend to stay the same and resist more alteration in error patterns whereas consonants contrasting in voicing are found to be perceived more similarly than consonants contrasting place or manner features (Steriade 2008). Data from cross-linguistic studies have also shown that voicing is not a feature that can be violated easily in speech error patterns. In particular, this finding is strongly confirmed by Jaeger's (2004) pattern for children's errors in English. Jaeger made a related point and suggested that the place feature is the feature most commonly involved in speech errors of English-speaking children, which is partially due to the fact that the place feature is the easiest to violate, partially due to the frequency factor. A manner difference between consonant pairs is considered a larger phonetic distinction than a place difference, and a voicing violation is regarded as a rather major mismatch between consonant pairs, and thus consonants that differ in voicing are less likely to interact in an error.

As for the underrepresentation in the feature [place], the special status of labiality and the special status of coronals have been attested in several different kinds of evidence involving typology, phonological processes (i.e., palatalization, consonant harmony), acquisition, speech errors, or aphasia studies (Paradis & Prunet 1991, Selkirk 1993). Wan (2002) and Hsu (2011) both showed the psychological validity of the underspecification of coronals, suggesting that speakers of Mandarin use underspecified representations on line during language production, and also showed that coronals, being different from consonants formed at other places of articulation, yield an asymmetrical behavior in phonological patterns.

In conclusion, this paper has outlined that the similarity of consonants as defined by the number of shared features influences the frequency with which two segments are mutually involved in errors. This property has been shown to occur in speech errors in every language for which data are available. In addition, the feature involving place of articulation is the feature most often violated by speech errors, and nasality is violated least often. Despite the small size of this corpus, the data have shown the same basic patterns as those in English and German, suggesting that the hierarchy of feature distribution may have some cross-linguistic validity, and possibly be related to the number of expected feature violations in phonological inventories or in the spoken corpus. In the near future, this research will extend to look into feature patterns in more detail. Place features can be subdivided into labials, dentals, retroflexes, palatals and velars; manner features can be broken down into plosives, nasals, fricatives, affricates, glides and liquids; voice onset time can be sub-categorized as aspiration, unaspiration, and voicing. Take features of place, for instance. Labials also have special status in several languages and Zuraw & Lu (2009) found that the co-occurrence restrictions in Muna labials are not driven by markedness constraints while those in Taglog labials are driven by markedness. However, Wan (2014) has presented acquisition data showing that Mandarin children are more likely to acquire labials and coronals at the same time, yet they use more coronals in replacing all other segments in Mandarin. In the near future, it would be interesting have more external evidence such as acquisition or aphasic studies in Mandarin reveal whether markedness plays a role in error distributions and whether the unmarked features are more likely to replace the marked ones, or vice versa.

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華語子音語誤之區辨特徵

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本研究主要是透過台灣華語自然語誤語料庫來測試子音中的區辨特徵，是否在不同特徵群組中的階級組織具備心理學驗證。

子音的區別特徵區分為 5 大類別，分別是[Place]，[VOT]，[Continuancy]，[Frication]，[Nasality]。結果發現，主要的語誤在子音代換中只呈現一個區辨特徵的不同，隨著區辨特徵差別越多，子音語誤代換的情形隨之遞減。此點顯示出越是相近似的子音越容易出現在子音語誤的代換錯誤，而子音之間[Place]是最容易被違反的，最不容易被違反的是[Nasality]。這樣的論點與其他語言語誤相關研究吻合，也稍微能從優選理論得到解釋。

關鍵詞：語誤、語音近似度、子音區辨特徵、華語