CHINESE UNIVERSITY OF HONG KONG

The Effects of Occurrence Frequency of Phonemes on Second Language Acquisition:

A Quantitative Comparison of Cantonese, Mandarin, Italian, German and American English

LIN1002 Invitation to Linguistics

by

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Contents

ABSTRACT

In second language acquisition, learners often replace foreign and unfamiliar sounds in the second language with the ones available in their first language. These replacements are obviously not random; however, what determines how learners replace foreign sounds? The present study is interested to find out the rules governing these replacements, particularly by analyzing common replacements in five target languages and by comparing the articulatory features between the original foreign sounds and the replacing sounds; and see if the occurrence frequency of the phonemes available in the first language would affect the results of these replacements.

1. INTRODUCTION

It is widely known that in the course of second language acquisition (SLA), a learner's knowledge of the second language (L2) is often influenced by his first language (L1). This statement applies to the different aspects of language learning, from phonetics to morphology, from syntax to pragmatics. The present study is interested in looking at how L1 influences a learner's L2 pronunciation.

Different languages select different sets of phonemes from the stock of possible sounds human can articulate. As a result, a learner in SLA would often encounter sound segments in L2 which his L1 does not make use of. In such a case, the learner would tend to replace these unfamiliar sounds with the ones available in his L1. What is interesting about this process is how we select replacements for these foreign sounds. It is obvious enough that we do not select replacements randomly, otherwise we could not possibly be able to tell one's mother tongue simply by the *accent* of his L2. Instead, it is reasonable to assume that we select replacements as *similar* as possible to the replaced sounds. The question in hand, then, becomes how we measure the *similarity* of sounds.

As learning how to pronounce a sound segment is basically learning how to make a certain posture with the articulators, it follows that the differences in different sound segments, or the similarity among them, lie in their articulatory features.

On the other hand, among the sounds available in the selected set of a language, or the phonemic stock of it, some occur more often than the others, while some occur so infrequently that their phonemic status may be doubtful. As replacement is a process of replacing foreign sounds with *familiar* sounds, it is thus natural to ask how large the effect of the occurrence frequency of the phonemes on the process of replacement is. In other words, is a similar but less frequent sound or a dissimilar but more frequent sound more likely to be selected as a replacement?

In order to suggest an answer to the above question, the present study is going to compare the occurrence frequency of phonemes in five languages, namely Cantonese, Mandarin, Italian, German and American English, and study the common replacements in them.

2. METHODOLOGY

In order to study the effects of occurrence frequency on replacement, a corpus for each of the five languages was prepared (Appendix A). The corpora were analyzed computationally to obtain the occurrence frequencies.

For Cantonese and Mandarin, the corpus data came with phonetic transcriptions. For Italian and German, the texts were analyzed based on their spellings. Since both languages are written with rather consistent phonetic alphabets, pronunciations of the words can be computed with a reasonable accuracy. The English data were linked to a database containing the phonetic transcription of each word, and the frequency was counted based on the phonetic transcriptions.

Since the corpora were considerably large (Appendix C.1-C.5), the number of phonemes analyzed was significant to reflect the frequency distribution of each language.

The present study has adopted the phoneme stock of Cantonese proposed by "The Cantonese Transliteration Scheme." For Mandarin, the stock is based on the Pinyin scheme and the analysis of vowel phonemes by Cao (2002; 24), with the modification that initial /j/ and /w/ in rhymes are regarded as realizations of consonantal /j/ and /w/ respectively, instead of vocalic /i/ and /u/. This greatly simplifies the stock of diphthongs in the language.

The phoneme stock and the phoneme-letter correspondence for Italian are based on the analysis by Batinti (1993: 37-38). There are, however, four major cases where a letter in Italian corresponds to two different phonemes, namely 'e' for /e/ and /ɛ/, 'o' for /o/ and /ɔ/, 's' for /s/ and /z/, and 'z' for /ts/ and /dz/. Nevertheless, since the occurrence frequency of /e/, /o/, /z/ and /dz/ are very insignificant compared with their counterparts (Batinti: 1993; 25-29), all occurrences of 'e', 'o', 's' and 'z' are treated as /ɛ/, /ɔ/, /s/ and /ts/ respectively.

German has a similar problem in phoneme-letter correspondence. Since earlier studies of the occurrence frequency of these correspondences are lacking, the "minor

phonemes" are assumed to be insignificant in frequency because most of them appear only in loan-words. The phoneme stock is partially adopted from Wiese (1996).

The phoneme stock of English is based on *The CMU Pronouncing Dictionary* (Carnegie Mellon University).

Since the features of consonants are more diverse and generally more distinctive than those of vowels, which eases the comparison between them, the present study will thus limit its scope to the study of replacement among consonants.

3. HYPOTHESIS

A high occurrence frequency of a phoneme in a language means that the speakers of this language articulate this particular sound more frequently than other sounds, and are thus more *familiar* with the articulation of this sound.

Since in replacement, we tend to replace a foreign sound with a more *familiar* one, it is thus reasonable to hypothesize that occurrence frequency plays a role in determining what sounds we choose as replacements. More precisely, a sound of higher occurrence frequency in L1 is more likely to be selected as a replacement for a foreign sound in L2.

The process of replacement, however, cannot possibly rely only on the occurrence frequency. Otherwise, the most frequent sound would have been selected as a replacement for every foreign sound. Therefore, there should be a set of rules determining how *similar* two sounds are. These rules and the effects of occurrence frequency are juxtaposed to determine the result of replacement.

4. DATA ANALYSIS

Phonemes can be grouped by their place of articulation and manner of articulation, and a comparison of occurrence frequency of the target languages with respect to these features may give us a hint to the characteristics of these languages. Referring to

Appendix D, it can be seen that each language focuses its articulation more or less in a certain part of the mouth, and its manner of articulation in one or two types.

For instance, Cantonese sounds are frequently produced further back in the throat, mostly palatal, velar and glottal. Alveolar phonemes are common but not particularly high in frequency, while phonemes in the post-alveolar and pre-palatal regions are basically lacking, although Cantonese speakers do sometimes realize the alveolar affricates as post-alveolar affricates. Compared to Mandarin, Cantonese flavors plosive and lateral consonants more, while affricates and approximants are less common.

On the other hand, Mandarin concentrates its articulation in the palatal region, with the tongue varying slightly in posture, such that three major places of articulations can be identified, namely alveolo-palatal, retroflex and palatal. Bilabial phonemes have high frequency also, mainly due to the frequent occurrence of the labial-velar approximant /w/. On the other hand, alveolar phonemes are relatively infrequent in Mandarin, especially when compared cross-linguistically.

Italian has a very interesting distribution in its occurrence frequency. It has more than 70% of its sounds produced in the alveolar region, and more than 10% in bilabial. This means that roughly four fifths of its sounds are produced in two very close areas, and is perhaps why Italian is usually spoken so fast by the speakers. Apart from the velar plosives and the very infrequent palatal consonants, Italian sounds are produced in the very front regions in the mouth, with very notable frequencies of the nasal /n/, trill /r/, plosive /t/ and lateral /l/.

German and English, being both Germanic languages, share quite a lot of similarities in their frequency distribution. What distinguish them apart are the presence of the inter-dental fricatives in English, the uvular trill in German, and the much more frequent approximants (/j/ and /w/) in English. Opposed to what is commonly believed, German sounds, like the English ones, are more concentrated in the front regions. The only prominently frequent sound produced at the back is the uvular trill, which is what gives German its usual impression. Fricatives and nasals are common both languages.

5. RULES OF SOUND REPLACEMENTS

Some most common sound replacements of produced by Cantonese L1 speakers acquiring different L2s are listed below.

L2	Mandarin	Italian	German	English
Common Replacements	/ɻ/ → /j/	/ʎ/ → /j/	/ʀ/ → /h/	/ɻ/ → /w/
	/x/ → /h/	/ʎ/ → /l/	/v/ → /w/	/v/ → /w/
	/x/ → /k^h/	/r/ → /l/	/ç/ → /h/	/θ/ → /f/
	/tʂ/ → /ts/	/ɲ/ → /j/	/x/ → /h/	/ð/ → /t/
	/$tʂ^h$/ → /ts^h/	/v/ → /f/	/z/ → /s/	/dʒ/ → /tʃ/
	/tɕ/ → /ts/	/d/ → /t/	/v/ → /f/	/z/ → /s/
	/$tɕ^h$/ → /ts^h/	/b/ → /p/	/d/ → /t/	/v/ → /f/
		/g/ → /k/	/b/ → /p/	/d/ → /t/
			/g/ → /k/	/b/ → /p/
				/g/ → /k/

Table 1. Common Replacements made by Cantonese L1 Speakers

If the original sounds and the replacing sounds in these replacements are compared in their articulatory features, the following table can be obtained.

No.	Replacements	Voice	Place	Manner
1	/b/ → /p/	●		
2	/d/ → /t/	●		
3	/dʒ/ → /tʃ/	●		
4	/g/ → /k/	●		
5	/v/ → /f/	●		
6	/z/ → /s/	●		
7	/ɻ/ → /j/		●	
8	/ɻ/ → /w/		●	
9	/tɕ/ → /ts/		●	
10	/$tɕ^h$/ → /ts^h/		●	
11	/tʂ/ → /ts/		●	
12	/$tʂ^h$/ → /ts^h/		●	
13	/x/ → /h/		●	
14	/θ/ → /f/		●	
15	/ç/ → /h/		●	
16	/ʎ/ → /j/			●
17	/r/ → /l/			●

Table 2. Forgoing of Articulatory Features in Replacement

Table 2 shows in each replacement process, what articulatory feature is forgone. For instance, in the process /ç/ → /h/, the two sounds are the same in terms of their voicing and manner of articulation (fricative). The only feature that they differ in is the place of articulation. Therefore, the feature forgone is the place of articulation.

With a few exceptions which we will deal with later and are not shown in Table 2, the data in Table 2 show an interesting phenomenon.

In processes 1 to 6, the replacing sounds are simply the voiceless counterparts of the original sounds. In processes 7 to 15, a counterpart of different voicing for the original sound is not present in the phoneme stock of Cantonese, therefore the same replacing strategy used above cannot be employed. Instead, the replacing sounds are of the same voicing and manner of articulation, with only the place of articulation changed. In processes 16 and 17, neither a voiceless counterpart of the original sound nor any sound with the same manner of articulation exists in the Cantonese phoneme stock. The replacing sounds then keep the same voicing and place of articulation, and forgo the manner of articulation.

What this suggests is that the process of replacement follows a set to rules to look for a "most similar" substitute for the original foreign sound, namely, a learner:

1. looks for a sound in his L1 which has the same place of articulation and manner of articulation; if such a sound is not found, he
2. looks for a sound in his L1 which has the same voicing and manner of articulation; if such a sound is not found, he
3. looks for a sound in his L1 which has the same voicing and place of articulation.

With the consideration of the frequent replacements /p^h/ → /p/, /t^h/ → /t/ and /k^h/ → /k/ made by L1 speakers of languages like Italian and Japanese acquiring English as L2, it can be generalized that the articulatory features are ranked in their readiness of being forgone, in decreasing order:

Articulation > Voicing > Place of Articulation > Manner of Articulation

6. EFFECTS OF OCCURRENCE FREQUENCY

As mentioned above, there are a few cases which the replacement rules cannot explain correctly. They are, namely, the following five processes[1]:

1. /x/ → /k^h/
2. /ɲ/ → /j/
3. /v/ → /w/
4. /ʎ/ → /l/
5. /ð/ → /t/

The forgone features of these replacements are shown in the following table:

No.	Replacements	Voice	Place	Manner
18	/x/ → /k^h/			●
19	/ɲ/ → /j/		●	●
20	/v/ → /w/		●	●
21	/ʎ/ → /l/		●	●
22	/ð/ → /t/	●	●	●

Table 3. Forgoing of Articulatory Features in Replacement (2)

While /x/, /v/ and /ʎ/ have the more favorable replacements /h/, /f/ and /j/ respectively, they are sometimes alternatively replaced by /k^h/, /w/ and /l/. The process /ɲ/ → /j/ is problematic because the rules predict that /ɲ/ should be replaced by /n/ or /ŋ/ instead. The process /ð/ → /t/ actually gives up all the three features while there can be better alternatives.

To account for these exceptions, it seems necessary to relate these processes to the characteristics of Cantonese's phoneme frequency distribution we described earlier.

For instance, Cantonese has a relatively high frequency in plosive consonants. The result of this is the increased tendency to replace Mandarin /x/ with /k^h/, a velar

plosive. For example, some Cantonese L1 learners pronounce /pʰu^{21}.tʰoŋ^{55}.xua^{51}/ “Mandarin” as [pʰu^{21}.tʰoŋ^{55}.kʰua^{51}].

The processes /v/ → /w/ and /ʎ/ → /l/ can be explained with similar reasons. Velar consonants and approximants are both frequent in Cantonese, while dental consonants are rare. As a result, there is a decreased tendency to replace /v/ with /f/ and an increased tendency to replace /v/ with /w/. This replacement occurs in English words like “very”, which is often pronounced as ['weɻɪ], for example. On the other hand, alveolar and lateral consonants are both frequent, and thus the tendency for the process /ʎ/ → /l/ is increased. An example is the replacement of the Italian word *gli* “the” /ʎi/ to /li/.

While Cantonese has both /n/ and /ŋ/, neither of them is frequent[2]. The result is that these phonemes are not potential replacement sounds in Cantonese, as if they do not even exist in the phoneme stock. Therefore, /ɲ/ is often replaced with /j/, a rather frequent approximant having the same place of articulation. As a result, Cantonese learners of Italian typically pronounce the word *gnocchi* “potato dumplings” /'ɲɔki/ as ['jɔki]. In contrast, the nasal consonants are very frequent in English, so that the phoneme /n/ is readily available for replacing /ɲ/. Therefore, English speakers tend to pronounce *gnocchi* as ['nɔki].

The case of the voiced inter-dental fricative /ð/ is also interesting. This is because while its voiceless counterpart /θ/ is able to find a replacement (/f/) relatively easily, it is unable to do so due to the lack of voiced /v/ in Cantonese. As plosives are more common than other types of manner of articulation, the alveolar plosive /t/ is often selected as a replacement. It should be noted, while the affricate /ts/ is more frequent than /t/, the total frequency of plosives is higher than that of affricates. On the contrary, Mandarin learners are more often to replace /ð/ with /ts/, because affricates are very frequent in the language. This suggests that the total frequencies of the manners of articulation play at least as much role as the frequencies of individual phonemes.

7. LIMITATIONS AND FUTURE STUDIES

There are a number of difficulties and limitations in the present study which might make the result arguable to some degree. These include the difficulties in determining the phonemes from the spelling and in determining the phonemes available in a language.

The first problem is a relatively minor one. As explained earlier, although the same letter may correspond to different phonemes in Italian and German, the frequencies of the "minor" phonemes are comparatively low and can be ignored without affecting the figures too much.

The second problem, on the other hand, is more troublesome. The phonemic status of a sound is sometimes hard to determine. For instance, [ç] and [x] are traditionally regarded as allophones of the phoneme /ç/ in German, while /h/ is a separate phoneme in its own right. Some linguists, however, argue that [x] and [h] should be allophones of the same phoneme and /ç/ is a separate phoneme instead, because [x] never occurs word-initially and [h] never word-finally, while [ç] can occur both word-initially and word-finally. The analysis of phoneme stocks is critical to the result of the study because it may alter the frequency distributions.

A more ideal way to solve this problem is perhaps to conduct the study using the realized allophones as the target for statistics. Since what we articulate are indeed the realized allophones, not the abstract phonemes, using allophones for statistics reflects the frequency distribution most honestly. It also eliminates the above-mentioned problem on determining the phonemic status of a sound. However, the scale and difficulty of the study will greatly increase if allophone frequency is to be counted, because we either have to depend solely on carefully transcribed corpora, or on very sophisticated rules on determining the allophones from written texts.

Last but not least, it should be pointed out that how a learner replaces sounds may not only depend on the articulatory similarities between these sounds. There are other factors to be considered, such as the perceptual similarities between them, and orthography.

For instance, while Spanish has the voiced phoneme /d/ and in fact an allophonic [ð], Spanish learners of English tend to replace /ð/ with the voiceless /t/ instead. This is most probably because when these Spanish learners learn English, they pronounce the English words according to the spelling, but following the Spanish rules. Since the letter 'h' is not pronounced at all in Spanish, when they read English words like *that*, *the* and *those*, they simply ignore the letter 'h' and pronounce them as if they were *tat*, *te* and *tose*, thus pronouncing the initial /ð/ as /t/.

8. CONCLUSION

The replacement rules suggested above are indeed parallel to our intuition. In both articulatory and perceptual terms, voicing and aspiration are less significant in differentiating sounds. Therefore when a replacement process undergoes, the first features to forgo are naturally voicing and aspiration. As the manner of articulation determines largely the quality of the sound produced, it is most reluctant to be forgone. Thus we have the hierarchy:

Articulation > Voicing > Place of Articulation > Manner of Articulation

This hierarchy alone, however, does not tell the whole story. Occurrence frequency may alter the results of replacement when a certain phoneme has a high frequency or a certain group of phonemes (with a certain place or articulation or manner of articulation) has a high total frequency. In such case, there is an increased tendency for that phoneme or a phoneme in that group to be selected as the replacement. On the contrary, if the phoneme selected by the replacement rules is too low in frequency, there will be a decreased tendency for the sound to be actually used as a replacement.

Given these rules and the relevant data of occurrence frequency, it is then possible to predict how a learner speaking language A would pronounce the foreign sounds in language B, at least statistically speaking. Hopefully, this will be of great help to sound recognition software to "guess" the words uttered by non-native speakers who speak with accents.

ENDNOTES

[1] There is another exception /ʁ/ → /h/ which does not follow the rules. However, since the phoneme /ʁ/ is actually often realized as the allophone [ʁ] by German speakers, the process should better be understood as /ʁ/ → /h/, which does in fact follow the rules. The uvular trill /ʀ/ is sometimes replaced by /ɻ/ by Cantonese L1 learners who speak also English and have acquired the sound.

[2] It is widely known that Cantonese speakers often replace initial /n/ with /l/ and omit /ŋ/ initials in their own language. Therefore, while /n/ has an occurrence frequency of 1.59% and /ŋ/ 2.22%, their frequencies should be even lower for most speakers, as the corpus used is based on recordings from radio programs, whose speakers often pronounce these /n/ and /ŋ/ more consciously.

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APPENDIX A - Corpus Sources

- Cantonese
  - Hong Kong Cantonese Adult Language Corpus
    - Type: transcription from radio programs
    - http://shs.hku.hk/corpus/corpus.asp
- Mandarin
  - The Lancaster Corpus of Mandarin Chinese
    - Type: mixed written texts
    - http://bowland-files.lancs.ac.uk/corplang/lcmc/
- Italian
  - A collection of 900 web pages
    - Type: mixed written texts
- German
  - TIGER Corpus
    - Type: written texts from newspaper
    - http://www.ims.uni-stuttgart.de/projekte/TIGER/
- American English
  - A collection of fictions
    - Type: written texts from fictions
  - The CMU Pronouncing Dictionary
    - http://www.speech.cs.cmu.edu/cgi-bin/cmudict

APPENDIX B - Phonemic Distribution of the Target Languages

Manner of Art.			Bilabial	Interdental	Labiodental	Alveolar	Postalveolar	Alveolo-palatal	Reotroflex	Palatal	Velar	Uvular	Glottal
			C M I G E	C M I G E	C M I G E	C M I G E	C M I G E	C M I G E	C M I G E	C M I G E	C M I G E	C M I G E	C M I G E
Plosive	- voice	- asp.	p			t					k		
		+ asp.	pʰ			tʰ					kʰ		
	+ voice	- asp.	b			d					g		
Fricative	- voice			θ	f	s	ʃ	ɕ	ʂ	ç	x		h
	+ voice			ð	v	z	ʒ						
Affricate	- voice	- asp.				ts		tɕ	tʂ		(kw)		
		+ asp.				tsʰ	tʃʰ	tɕʰ	tʂʰ		(kʰw)		
	+ voice	- asp.					dʒ						
Nasal	+ voice		m			n				ɲ	ŋ		
Trill	+ voice					r						R	
Lateral	+ voice					l							
Approximant	+ voice		(w)						ɻ	j			
Lat. Approximant	+ voice									ʎ			

C: Cantonese
M: Mandarin
I: Italian
G: German
E: American English

APPENDIX C.1 - Statistics of Cantonese Phonemes

	Phoneme	Frequency	%
Pure Vowel	/ø/	5746	5.67
	/œ/	3116	3.08
	/ə/	5859	5.79
	/a/	14035	13.86
	/ɐ/	15581	15.39
	/ɛ/	12148	12.00
	/i/	18413	18.18
	/o/	3775	3.73
	/ɔ/	17947	17.72
	/u/	1582	1.56
	/y/	3069	3.03
		101271	100.00
Diphthong	/ai/	2239	5.49
	/au/	618	1.52
	/ɐi/	11168	27.39
	/ɐu/	6089	14.93
	/ei/	8340	20.45
	/ɛu/	7	0.02
	/iu/	1741	4.27
	/ou/	7879	19.32
	/ɔi/	1605	3.94
	/ui/	1093	2.68
		40779	100.00
Syll. Cons	/m/	5508	
	/ŋ/	107	
Consonant	/p/	3205	2.55
	/p^h/	961	0.76
	/t/	11234	8.93
	/t^h/	2854	2.27
	/k/	19370	15.40
	/k^h/	3088	2.45
	/kw/	534	0.42
	/k^hw/	76	0.06
	/f/	3090	2.46
	/m/	6917	5.50
	/ŋ/	2791	2.22
	/n/	1998	1.59
	/l/	13354	10.62
	/s/	8759	6.96
	/h/	12893	10.25
	/ts/	13566	10.78
	/ts^h/	3299	2.62
	/j/	13328	10.60
	/w/	4478	3.56
		125795	100.00
Coda	/-m/	6579	
	/-n/	12189	
	/-ŋ/	13913	
	/-k/	6301	
	/-p/	925	
	/-t/	5764	

Total Phonemes:	319131
Total Characters:	147665
Phonemes per Character:	2.16
Vowel-to-Consonant Ratio:	1:1.16

Vowels	
	%
Front:	41.96
Central:	21.17
Back:	36.87
Close:	22.77
Close-Mid:	15.19
Open-Mid:	32.79
Open:	29.24
Rounded:	34.79
Unrounded:	44.04
Neutral:	21.17

Consonants	
	%
Bilabial:	8.81
Labiodental:	2.46
Alveolar:	43.77
Palatal:	10.60
Velar:	24.12
Glottal:	10.25
Fricative:	19.67
Affricate:	13.41
Plosive:	32.85
Nasal:	9.31
Lateral:	10.62
Approximant:	14.15
Voiced:	34.08
Voiceless:	65.92

APPENDIX C.2 - Statistics of Mandarin Phonemes

	Phoneme	Frequency	%
Pure Vowel	/a/	87378	23.88
	/e/	79312	21.67
	/i/	108084	29.54
	/o/	36786	10.05
	/u/	42090	11.50
	/y/	12286	3.36
		365936	100.00
Diphthong	/ai/	17258	27.19
	/au/	22933	36.13
	/ei/	6222	9.80
	/ou/	8194	12.91
	/ya/	4402	6.94
	/ye/	4464	7.03
		63473	100.00

Vowels	
	%
Front:	54.57
Central:	23.88
Back:	21.55
Close:	44.40
Close-Mid:	31.73
Open-Mid:	0.00
Open:	23.88
Rounded:	24.91
Unrounded:	75.09
Neutral:	0.00

Consonant	/p/	18483	3.86
	/pʰ/	5081	1.06
	/t/	45215	9.44
	/tʰ/	15830	3.31
	/k/	21727	4.54
	/kʰ/	8007	1.67
	/f/	11668	2.44
	/m/	13310	2.78
	/n/	8862	1.85
	/l/	22719	4.75
	/x/	19735	4.12
	/tɕ/	31845	6.65
	/tɕʰ/	13991	2.92
	/ɕ/	23199	4.85
	/tʂ/	28244	5.90
	/tʂʰ/	13156	2.75
	/ʂ/	32357	6.76
	/ɻ/	9401	1.96
	/ts/	15618	3.26
	/tsʰ/	6009	1.26
	/s/	6641	1.39
	/j/	62200	12.99
	/w/	45460	9.50
		478758	100.00
Coda	/-n/	73868	
	/-ŋ/	71828	

Consonants	
	%
Bilabial:	17.20
Labiodental:	2.44
Alveolar:	25.25
Alveolo-Palatal:	14.42
Palatal:	12.99
Retroflex:	17.37
Velar:	10.33
Fricative:	19.55
Affricate:	22.74
Plosive:	23.88
Nasal:	4.63
Lateral:	4.75
Approximant:	24.45
Voiced:	33.83
Voiceless:	66.17

Total Phonemes:	1053863
Total Characters:	429409
Phonemes per Character:	2.45
Vowel-to-Consonant Ratio:	1:1.45

APPENDIX C.3 - Statistics of Italian Phonemes

	Phoneme	Frequency	%
Pure Vowel	/a/	1109061	21.86
	/ɛ/	1329216	26.20
	/i/	1357028	26.75
	/ɔ/	985794	19.43
	/u/	291868	5.75
		5072967	100.00

Vowels	
	%
Front:	52.95
Central:	21.86
Back:	25.19
Close:	26.75
Close-Mid:	0.00
Open-Mid:	45.63
Open:	21.86
Rounded:	25.19
Unrounded:	74.81
Neutral:	0.00

Consonant	/ɲ/	13506	0.25
	/ʎ/	31870	0.59
	/dʒ/	72709	1.35
	/ʃ/	13301	0.25
	/b/	78499	1.46
	/tʃ/	117750	2.19
	/d/	494053	9.19
	/f/	95528	1.78
	/g/	66460	1.24
	/k/	343579	6.39
	/l/	593796	11.04
	/m/	252828	4.70
	/n/	747083	13.89
	/p/	288240	5.36
	/r/	707001	13.14
	/s/	466607	8.68
	/t/	700456	13.02
	/v/	157485	2.93
	/ts/	137926	2.56
		5378677	100.00

Consonants	
	%
Bilabial:	11.52
Labiodental:	4.70
Alveolar:	71.52
Postalveolar:	3.79
Palatal:	0.84
Velar:	7.62
Fricative:	13.63
Affricate:	6.11
Plosive:	36.65
Nasal:	18.84
Trill:	13.14
Lateral:	11.04
Lateral Approximant:	0.59
Voiced:	59.78
Voiceless:	40.22

Total Phonemes:	10451644
Total Words:	1916731
Phonemes per Word:	5.45
Vowel-to-Consonant Ratio:	1:1.06

APPENDIX C.4 - Statistics of German Phonemes

	Phoneme	Frequency	%
Pure Vowel	/a/	131939	11.09
	/aː/	53509	4.50
	/ɛ/	187620	15.77
	/eː/	113509	9.54
	/ɪ/	124388	10.45
	/iː/	111529	9.37
	/ɔ/	70558	5.93
	/oː/	34284	2.88
	/œ/	6762	0.57
	/øː/	3320	0.28
	/ʊ/	84484	7.10
	/uː/	14956	1.26
	/ʏ/	19985	1.68
	/yː/	8663	0.73
	/ə/	61566	5.17
	/ɐ/	162796	13.68
		1189868	100.00
Diphthong	/aɪ/	62415	61.66
	/au/	27991	27.65
	/oy/	10814	10.68
		101220	100.00
Consonant	/b/	73963	3.69
	/p/	36391	1.82
	/d/	180228	8.99
	/t/	226024	11.28
	/g/	82149	4.10
	/k/	61680	3.08
	/v/	52589	2.62
	/f/	98270	4.90
	/s/	123773	6.17
	/z/	72884	3.64
	/l/	122112	6.09
	/m/	90180	4.50
	/n/	335567	16.74
	/ŋ/	31579	1.58
	/R/	223595	11.15
	/ʃ/	40206	2.01
	/j/	9021	0.45
	/ts/	46424	2.32
	/tʃ/	4999	0.25
	/ç/	40956	2.04
	/x/	18055	0.90
	/h/	33813	1.69
		2004458	100.00

Vowels	
	%
Front:	48.39
Central:	18.86
Back:	32.75
Close:	30.59
Close-Mid:	26.38
Open-Mid:	27.44
Open:	15.59
Rounded:	36.01
Unrounded:	45.13
Neutral:	18.86

Consonants	
	%
Bilabial:	10.00
Labiodental:	7.53
Alveolar:	55.23
Postalveolar:	2.26
Palatal:	2.49
Velar:	9.65
Uvular:	11.15
Glottal:	1.69
Fricative:	23.97
Affricate:	2.57
Plosive:	32.95
Nasal:	22.82
Lateral:	6.09
Trill:	11.15
Approximant:	0.45
Voiced:	63.55
Voiceless:	36.45

Total Phonemes:	3295546
Total Words:	603111
Phonemes per Word:	5.46
Vowel-to-Consonant Ratio:	1:1.55

APPENDIX C.5 - Statistics of American English Phonemes

	Phoneme	Frequency	%
Pure Vowel	/ɑ/	37346	5.29
	/æ/	75930	10.75
	/ʌ/	54891	7.77
	/ə/	162249	22.98
	/ɔ/	32568	4.61
	/e/	64709	9.16
	/ɚ/	55448	7.85
	/ɪ/	106522	15.09
	/i/	69561	9.85
	/ʊ/	10020	1.42
	/u/	36826	5.22
		706070	100.00
Diphthong	/eɪ/	31158	27.46
	/aʊ/	13506	11.90
	/aɪ/	39175	34.52
	/əʊ/	27338	24.09
	/ɔɪ/	2292	2.02
		113469	100.00

Vowels	
	%
Front:	52.71
Central:	22.98
Back:	24.31
Close:	31.57
Close-Mid:	32.14
Open-Mid:	20.24
Open:	16.04
Rounded:	11.25
Unrounded:	65.77
Neutral:	22.98

Consonant	/b/	39393	3.09
	/tʃ/	12231	0.96
	/d/	101262	7.94
	/ð/	70298	5.51
	/f/	37857	2.97
	/g/	16150	1.27
	/h/	46385	3.64
	/dʒ/	9566	0.75
	/k/	54096	4.24
	/l/	85017	6.67
	/m/	64541	5.06
	/n/	147295	11.56
	/ŋ/	23778	1.87
	/p/	39405	3.09
	/ɹ/	86465	6.78
	/s/	105575	8.28
	/ʃ/	16902	1.33
	/t/	146980	11.53
	/θ/	10133	0.79
	/v/	43148	3.38
	/w/	48895	3.84
	/j/	13726	1.08
	/z/	54700	4.29
	/ʒ/	914	0.07
		1274712	100.00

Consonants	
	%
Bilabial:	15.08
Labiodental:	6.35
Interdental:	6.31
Alveolar:	57.06
Postalveolar:	3.11
Palatal:	1.08
Velar:	7.38
Glottal:	3.64
Fricative:	30.27
Affricate:	1.71
Plosive:	31.17
Nasal:	18.48
Lateral:	6.67
Approximant:	11.70
Voiced:	63.16
Voiceless:	36.84

Total Phonemes:	2094251
Total Words:	593079
Phonemes per Word:	3.53
Vowel-to-Consonant Ratio:	1:1.56

APPENDIX D - Comparison of Occurrence Frequency with respect to the Place of Articulation and the Manner of Articulation

	Cantonese	Mandarin	Italian	German	English	Average
Bilabial	8.81	17.20	11.52	10.00	15.08	12.52
Interdental	0.00	0.00	0.00	0.00	6.31	1.26
Labiodental	2.46	2.44	4.70	7.53	6.35	4.70
Alveolar	43.77	25.25	71.52	55.23	57.06	50.57
Postalveolar	0.00	0.00	3.79	2.26	3.11	1.83
Alveolo-Palatal	0.00	14.42	0.00	0.00	0.00	2.88
Retroflex	0.00	17.37	0.00	0.00	0.00	3.47
Palatal	10.60	12.99	0.84	2.49	1.08	5.60
Velar	24.12	10.33	7.62	9.65	7.38	11.82
Uvular	0.00	0.00	0.00	11.15	0.00	2.23
Glottal	10.25	0.00	0.00	1.69	3.64	3.11
						100.00

Comparison of Occurrence Frequency with respect to the Place of Articulation

	Cantonese	Mandarin	Italian	German	English	Average
Plosive	32.85	23.88	36.65	32.95	31.17	31.50
Fricative	19.67	19.55	13.63	23.97	30.27	21.42
Affricate	13.41	22.74	6.11	2.57	1.71	9.31
Nasal	9.31	4.63	18.84	22.82	18.48	14.82
Trill	0.00	0.00	13.14	11.15	0.00	4.86
Lateral	10.62	4.75	11.04	6.09	6.67	7.83
Approximant	14.15	24.45	0.00	0.45	11.70	10.15
Lat. Approximant	0.00	0.00	0.59	0.00	0.00	0.12
						100.00

Comparison of Occurrence Frequency with respect to the Manner of Articulation

Legends:	well over avg	over avg	below avg	well below avg