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Speech spectrum analysis of English and Mandarin : implications for hearing aid evaluation

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Implications for hearing aid evaluation**

Tu, Clara, M.A.

San Jose State University, 1991

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**SPEECH SPECTRUM ANALYSIS OF ENGLISH AND MANDARIN:
IMPLICATIONS FOR HEARING AID EVALUATION**

**A Thesis
Presented To
The Faculty of the Division of
Special Education and Rehabilitative Services
Program in Communication Disorders and Sciences
San Jose State University**

**In Partial Fulfillment
of the Requirements for the Degree
Master of Arts**

**By
Clara Tu
December, 1991**

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ABSTRACT

SPEECH SPECTRUM ANALYSIS OF ENGLISH AND MANDARIN: IMPLICATIONS FOR HEARING AID EVALUATION

By Clara Tu

The speech spectrum derived from English speakers has been commonly used in calculating desired gain in hearing aid evaluation and fitting. However, if different languages have different speech spectra, then these differences should be taken into consideration when prescribing real-ear gain or functional gain. The purpose of this study was to conduct a speech spectrum study using twenty English and twenty Mandarin speakers to determine and compare the spectral energy of the two spectra. Each language group consisted of ten male and ten female speakers. Two-and-a-half-minute speech samples were collected from each subject.

Results indicated that the shapes of the generated English and Mandarin spectra were similar. Implications for hearing-aid fitting were discussed.

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CHAPTER I

INTRODUCTION

The goal of aural rehabilitation is to improve the communicative ability of an individual with a hearing loss. A major component of the rehabilitative strategy involves the selection, evaluation and fitting of a hearing aid. It is hoped that a hearing aid will increase the availability of acoustic cues, thereby improving the speech recognition of the hearing impaired individual in a variety of listening situations. In the traditional hearing aid evaluation, the audiologist selects several hearing aids with similar electroacoustic characteristics and administers various pure-tone and speech tests to the patient with and without the hearing aid(s) (Carhart, 1946). The final choice of a hearing aid is based upon patient performance with each hearing aid. Recent evidence has demonstrated, however, that hearing aids with similar characteristics probably cannot be differentiated with standard audiologic tests (Walden, Schwartz, Williams, Holum-Hardeggen & Crowley, 1983).

Currently, the hearing aid evaluation procedure involves the *a priori* selection of a hearing aid based upon several factors. These factors may include the long-term average speech spectrum, normal comfortable-loudness-level contour, preferred listening levels, low-frequency room noise, loudness discomfort level, earphone versus unaided sound field thresholds, and prescribed real-ear gain. Although the long-term average speech spectrum is useful for prescribing and validating hearing aid fittings, it is uncertain if phonetic and/or acoustic differences occurring in different languages affect the long-term average speech spectrum.

The long-term average speech spectrum, which is one of the major factors considered in the prescriptive fitting of hearing aids, refers to the overall RMS (Root Mean Square) level and shape of speech energy chosen to represent everyday speech. The RMS level of a signal is obtained by taking the peak-to-peak voltage and dividing it by the square root of two. Two characteristics of the speech spectrum, overall RMS and shape, have been thoroughly investigated for English.

With regard to overall RMS, French and Steinberg (1947) reported a 30 dB dynamic range for speech with the highest levels about 12 dB above the average and the lowest levels about 18 dB below the long-term average level. They also found the overall level to be approximately 60 dB sound pressure level (SPL) at 1 meter from the lips of the speakers at a normal conversational voice level. More recent estimates (Cox, 1983; Pascoe, 1978) have placed the overall RMS level of speech between 65 and 75 dB SPL. Although the overall levels of the English speech spectrum have varied, the shape of the spectrum remains relatively stable across investigations. French and Steinberg (1947) proposed an Articulation Index (AI) theory to quantify the acoustic cues available from the speech spectrum, and this theory recently has been modified for predicting the percentage of available speech cues perceived via hearing aids (Pavlovic, 1989).

Statement of the Problem

Since differences in long-term speech spectra usually translate into equal differences in prescribed gain, any differences between speech spectra have an impact on a hearing aid evaluation. Specifically, Olsen,

Hawkins and Van Tassell (1987) asserted that the assessment of speech audibility is based on two sets of data: (1) an estimate of the average level of speech as a function of frequency (speech spectrum), and (2) auditory sensitivity of the patient throughout the frequency range encompassed by the speech spectrum. If the first set of data changes due to the possible differences in the estimates as a result of different languages, then it can be inferred that the assessment of speech audibility might require a different strategy for a hearing aid evaluation in a different language speaking population. That is, if audiologists consider the energy in the English speech spectrum when determining the desired amplification characteristics of a hearing aid, then people who use languages other than English to communicate in everyday situations may not benefit from this strategy if the speech spectrum of their own language contains significant differences. It is the contention of this study that the hearing aid fitting for the specific language population should take the characteristics of that language's speech spectrum into consideration and thus benefit the hearing aid wearer's listening and communicative ability.

Hypothesis. As measured by the comparison between the two generated speech spectra (English and Mandarin), there will be a significant difference between the speech spectrum of the English speakers and the speech spectrum of the Mandarin speakers.

Statement of the Purpose

The goal of this research was to measure the long-term average speech spectrum using 20 English speakers and 20 Chinese Mandarin dialect speakers in order to determine the spectral energy characteristics of English

and Mandarin, and to make suggestions for hearing aid selection and evaluation techniques for the Mandarin-speaking population.

Research Questions

1. What are the spectral energy characteristics of Mandarin?
2. How does the spectrum of Mandarin differ from the spectrum of English?
3. What are the implications for optimizing the benefit if the English spectrum is used for Mandarin speakers in hearing aid fitting?
4. Based on the generated data, what implications exist for hearing aid evaluation and fitting strategies with the Mandarin-speaking population?

CHAPTER II

SURVEY OF RELATED LITERATURE

Introduction

The primary goal of present aural rehabilitation and amplification methods is to maximize the use of residual hearing for speech (Olsen et al., 1987). One of the factors used in calculating desired amplification levels, also referred to as real-ear or functional gain, is the speech spectrum. The speech spectrum is defined as the overall RMS level and configuration of speech energy chosen to represent everyday speech. Although the speech spectrum derived from English speakers is appropriate for use in prescriptive formulas that calculate the desired hearing-aid gain for an English-speaking population, it may not be appropriate for calculating amplification levels for those patients who communicate in languages other than English. Specifically, if different languages have significantly different speech spectra, then these differences should be accounted for when prescribing real-ear gain or functional gain for the population that uses that specific language. The purpose of this research was to conduct a speech spectrum study with twenty English and twenty Chinese Mandarin dialect speakers in order (1) to determine the spectral energy characteristics of Mandarin, (2) to compare spectral characteristics of Mandarin with those obtained from English speakers, and (3) to make suggestions for hearing aid selection and evaluation techniques for people who use languages other than English to communicate in everyday situations.

Acoustic Analysis of Mandarin

The word "Mandarin" refers to the major dialect family of China. It is an established linguistic term in the West. Mandarin also represents the speech of Beijing, which for centuries has been recognized as the standard dialect of China because of the political and cultural significance of the city.

Li and Thompson (1981) noted that the structure of the Mandarin syllables can be divided into three components:

(1) The initials:

Mandarin syllables either begin with a single consonant or no initial consonant at all. Mandarin does not have consonant clusters. There are 22 initials in Mandarin (Table 1). Svantesson (1986) conducted an acoustic

Table 1

The Consonantal Initials in Mandarin

	Unaspirated Stops	Aspirated Stops	Unaspirated Affricates	Aspirated Affricates	Nasals	Fricatives	Voiced Continuants
	Pinyin	Pinyin	Pinyin	Pinyin	Pinyin	Pinyin	Pinyin
Bilabials	b	p			m		
Labio- dentals						f	
Dental- alveolars	d	t	z	c	n	s	l
Retroflexes			zh	ch		sh	r
Palatals			j	q		x	
Velars	g	k				h	

analysis of the six fricatives and the fricative components of the six affricates using four male native speakers of Mandarin. The recordings

were made in sound-treated rooms in Lund and in Stockholm. Frequency spectra were obtained by using the Fast Fourier Transform (FFT) and then analyzed in critical bands. The findings were that the /s/ and the /x/ sounds in Mandarin peaked in the 5000 to 9000 Hz region, with /s/ having a much more abrupt fall than the /x/ down toward the 3000 and 5000 Hz and a lower intensity than the /sh/ and /x/ sounds. In the spectra of the /sh/ sound, the overall pitch level fell in the 2000-3000 Hz region with an increasing flatness in the configuration as compared to the /s/ and /x/ sounds. Both /f/ and /h/ sounds had a flatter and lower level than those of the sibilants. However, the only voiced fricative, /r/, contained energy in the 1000 Hz bands and 2700 Hz region. Svantesson also concluded that the fricative components of the affricates were similar to the corresponding fricatives.

(2) The finals:

There are 37 finals in Mandarin that are predominantly vowels. The only two consonants that occur exclusively in final position are the velar nasal and the alveolar nasal.

(3) The tones:

There are 4 tones in the Mandarin dialect. Each tone is a relative, contrastive pitch pattern that is associated with a syllable, i.e., a syllable of the same consonantal and vocalic makeup with a different tone sounds like a totally different word. Quite similar to the glides /w/ and /j/ in English, the energy or formants surrounding the pitch contours are subject to their interaction with the neighboring sounds. A formant is a measured concentration of sound energy in a limited frequency region and is

characterized by both the source of the sound and the acoustic resonating cavity. Table 2 illustrates the four tones.

Table 2

The Four Tones in Mandarin

Tone	Description	Pitch	Graph	Example
1	high level	55		yī "clothes"
2	high rising	35		yí "to suspect"
3	dipping/ falling rising	214		yǐ "chair"
4	high falling	51		yì "meaning"

Comparison of English and Mandarin Phonetics

Phonetically, English and most European speech is characterized as a stream of phonetic elements corresponding roughly to vowel and consonant sounds. English words are made up of one or more syllables with a stressed syllable whenever there is more than one syllable. Pitch contours are used syntactically to indicate speaker's intention of communication in sentences and lexically to differentiate word meaning. For instance, a question is usually uttered in a rising pitch contour in the end of the sentence and the word "progress" is used differently with stress in the first syllable or the second syllable. English is an intonation language because the pitch contour is important in sentences and some words. In contrast, Mandarin is a tone language since the pitch of individual syllable is used to contrast meaning by means of pitch variation.

Most of the languages in the world are tone languages. In Africa alone, there are more than one thousand tone languages. Most Asian languages, such as Chinese, Thai and Burmese, and many American Indian language are also tone languages. In some tonal languages, the pitch of each tone remains at a constant frequency, whereas in other tonal languages, the direction of pitch plays an important role in the phonology and semantics of these languages. Tones that glide from a high to a low pitch or from a low to a high pitch are known as contour tones. Tones change vowels that are usually identified by the first and second formants. Vowels have more low frequency energy and occur at higher levels than consonants. All of the vowels can be identified by the first two formants produced by the vocal tract, the lowest frequency formant being the first formant and the next lowest frequency formant, the second formant. Since Mandarin words or morphemes are made up of one syllable that ends predominantly in vowels or in the two nasal sounds, and never end in plosives, stops, fricatives nor affricates, lower frequency energy may play a major role. The four tones in Mandarin serve as markers on the syllables that contrast the meaning of words. A tone changes the fundamental frequency of the morpheme resulting in the variation of the pitch and thus alters the meaning of the word. On the contrary, English has lexical stress that denotes word meaning.

The English consonants contain energy primarily in the frequency region between 250 to 8,000 Hz. Fricatives and affricates in Mandarin contain energy that spreads across a wider frequency region (e.g., bands

from 1000 Hz to 9000 Hz) as compared to 3000 Hz to 8000 Hz for English fricatives and affricates.

Estimates of English Speech Spectra: Variability

Many estimates of the long-term average speech spectrum have been made using English speakers as subjects; however, the variability is substantial. Estimates have been reported that vary by as much as 19.5 dB for 125 Hz, 17 dB for 3000 to 6000 Hz, 14 dB for 2000 Hz, 13 dB at 8000 Hz, 11 dB at 250 and 1000 Hz, and 6.5 dB at 500 Hz. Additionally, estimates of the overall level of speech range from 55 to 70 dB SPL (Olsen et al., 1987).

According to Olsen et al. (1987), some variables that may account for the variability of speech signals include the following:

(1) Vocal effort of the speaker. In daily life people speak with vocal effort that ranges from casual voice to a shout. Low frequency energy is more intense than high frequency energy for casual and normal vocal effort; but for loud speech, the mid frequency energy is more intense. Pearsons, Bennett and Fidell (1978) reported that with increased vocal level, spectral shape changed in terms of a shift from 500 Hz to a greater high frequency (1600 Hz) content.

(2) Sex. The mean difference in overall speech level between male and female speakers producing speech with normal vocal effort is approximately 2 dB. Fletcher (1953) suggested that female speakers tend to emphasize sibilant sounds more than male speakers do; therefore, more energy in the higher frequencies may result. The major difference in the

spectra of both sexes was noted in a greater concentration of vocal energy below 200 Hz in the male speakers (Pearsons et al., 1978).

(3) Age. Children have been included in speech spectrum studies with adults (Niemoeller, McCormick & Miller, 1974; Pearsons et al., 1978), which may influence the results since children have a higher fundamental frequency (F_0) than adults.

(4) Choice of speech material. Whether the speech material contains an abundance of stops and fricatives or nasal sounds will affect the outcome of the speech energy. Also, the long-term spectra of nonsense syllables versus synthetic sentences may differ (Kamm & Dirks, 1982).

(5) Method of analysis. The width of the frequency bands within which the levels will be computed, the length of the sampled intervals and the distance and azimuth of the microphone from the speakers may affect the overall level of the speech. Cornelisse, Gagne and Seewald (1991) measured the long-term average speech spectrum at two different recording locations; one was 30 cm directly in front of the speaker and the other was at the tragus of the speaker's ear. They found that there were significant differences in the overall level and frequency spectra between the two different microphone positions.

(6) Speaker. An acoustical analysis of the speech signal in terms of long-term speech spectra may identify speakers of different languages. Majewski and Hollien (1975) used 50 American and 50 Polish college students to read a passage in the speakers' native language and analyzed the results with a cross-correlation statistical technique. They concluded

that the cross-correlation technique provided "very high levels" of identifying individuals from their speech.

Estimates of English Speech Spectrum: Individual Reports

An estimate of the long-term average speech spectrum was derived from the classic paper of Dunn and White (1940). Subjects consisted of six male speakers and six female speakers who read English stories continuously for 2.5 minutes. The sound was picked up by a condenser microphone situated at a distance 30 cm in front of the speaker's lips. The microphone was calibrated for free field pressures. Measurements of spectral energy were made in peak and RMS sound pressures in one-eighth-second intervals and in various bands of frequencies up to 12,000 Hz. Specifically, octave bands were used below 500 Hz and one-half octaves were used above 500 Hz. For frequencies above 8000 Hz, a high pass filter with an upper limit of 12,000 Hz was used since there was minimal speech energy in this region. The researchers then summed the energy from the short (1/8 second) intervals to derive the long-term values. Series 1 in Figure 1 illustrates the average long-term interval estimate across speakers converted to spectrum level. The findings from the Dunn and White study indicate that in the 125-500 Hz region, a 40-50 dB SPL level was measured and spectrum level above this region rolls off at approximately 9 dB per octave (Olsen et al. 1987).

Niemoeller, McCormick and Miller (1974) also measured the spectrum of spoken English in 1/3 octave bands for 10 men, 10 women and 6 children. Speech samples were collected by reading newspaper text and recorded in an anechoic chamber. The composite output of each of the

three groups was obtained by electronically mixing the speech samples using a 16-track tape recorder and then the three composite outputs were analyzed in 1/3 octave bands and converted to spectrum levels. They reported that their findings were similar to previous studies in that the average spectrum reached the maximum between 200-500 Hz and then rolled off in the higher frequencies at a rate of 8-10 dB per octave.

Byrne (1977) recorded a long-term speech spectrum using 15 men and 15 women Australian speakers. The speech material consisted of a passage from a popular magazine with a time course of about 2.25 minutes to just over 2.5 minutes. The spectrum in 1/3 octave band levels obtained from the study demonstrated a decrease in levels from 500 Hz to 1000 Hz and a relatively flat configuration from 1000 to 8000 Hz (Series 2 in Figure 1).

Pearsons et al. (1978) measured speech levels in various noisy environmental situations. Conversations were recorded and speech levels were determined in several different environments, including urban and suburban homes, hospitals, trains and airplanes. Measurements were obtained via a miniature microphone located near the ear in the bow of an eyeglass frame. The findings are summarized as follows:

- (1) Speech levels outside urban homes were measured at 65 dB SPL, and 57 dB SPL inside the homes.
- (2) Overall speech levels were found to be at 55 dB SPL for both outside and inside suburban homes.
- (3) In hospitals, 56 dB SPL overall level was observed.

(4) In trains and in airplanes, 66 dB SPL and 68 dB SPL were reported, respectively.

Pearsons and his colleagues in the same study also measured the levels and spectra for 100 speakers speaking a passage into the microphone that was located 1 meter from the speakers in an anechoic chamber. The overall mean levels of speech were 55 dB SPL for women, 58 dB SPL for adult men, and 58 dB SPL for children age 6-13.

Cox and Moore (1988) measured the long-term speech spectrum of English and evaluated the statistical differences between the Byrne (1977) and Pearsons et al. (1977) spectra. Subjects were 30 male and 30 female native speakers of American English. The results revealed that the speech spectrum by Byrne differed from the other two spectra (i.e., Pearsons et al.'s spectra and the spectra obtained by Cox and Moore), particularly in the 1000 Hz and 2000 Hz region for both sexes. Cox and Moore postulated that different vowels in the Australian versus the American English contributed to the differences. Also, the Pearsons et al. female spectrum was found to be significantly higher than the other two spectra in the 3000 Hz to 5000 Hz bands; they suggested that the differences have been related to the speech materials used, since the "Joe....lawn" passage used by Pearsons et al. contained six times more /sh/ and /zh/ phonemes. These sounds produce energy in the higher frequency regions. Additionally, in the same study of Cox and Moore, a composite measurement derived from the male and the female speakers produced a single long-term RMS one-third octave band speech spectrum representing an overall level of 70 dB SPL which was intended to be applied in hearing aid gain prescription

strategies. Series 3 in Figure 1 depicts the long-term RMS levels of speech used to represent speech in both the Pascoe and the Cox and Moore procedures for prescribing real-ear gain for hearing aids.

With the intention of determining if the speech spectrum in 1/3 octave bands or in decibels of pressure spectrum level (energy level within each third octave band) is more representative of the speech energy the ear uses for the perception of speech, Berger, Klich and Millin (1982) measured the speech spectrum in terms of dB pressure spectrum level (dB PSL) within 1/3 octave band intervals. Subjects were 16 college students (8 men and 8 women) who read a 15 word, 18 syllable second-order sentence. The sentence was constructed to contain all of the vowels, diphthongs and consonants in general American English, with the exception of the /zh/ sound. This sentence was believed to provide a representative sample of the speech sounds a hearing aid must amplify. The speech spectrum was translated to dB HL. They found that the greatest energy in speech was in the vicinity of 500 Hz, reflecting energy present in vowels at the fundamental frequency and their lower formants, and gradually decreased (8-12 dB/octave) in the higher frequencies. The investigators concluded that an ear or an amplified ear does not respond equally across all frequencies to understand speech signals, but the specific relationship between certain frequency bands and intelligibility remained unclear.

In order to describe the effects of open-ear, normal listening on the speech spectrum, Pascoe (1978) measured the sensation levels of speech of 20 young normally hearing students by using a behavioral paradigm. The subjects were to listen to a tape recording of speech of 10 men and 10

women prepared by Niemoeller via sound field through an equalizer to maintain a flat frequency response. The spectra and levels of this recording represented the long-term average spectrum of speech. Presentation level of a signal of broadband response and 1/3 octave band speech signal responses were controlled by the listener through a Bekesy audiometer. The broadband level was calibrated at 75 dB SPL for 0 dB attenuation measured at 0° azimuth of the listener's head. The task required of the listener was to press the attenuator control until the signal was no longer audible and then track the thresholds. Since the amount of attenuation to reach threshold equals to the sensation levels (SL) of the unattenuated band levels, the SL for each of the 1/3 octave band represents the hearing level of each band perceived by the normal listeners.

Summary of Pascoe's speech spectrum study is as follows:

- (1) The mean sensation level for the broad band signal was 63 dB.
- (2) The highest 1/3 SL for summed speech occurred at 630 Hz region and 2500 Hz region with a less than 3 dB difference between the peaks of these two bands. Pascoe referred to this as the "two-humped" distribution of normal SL for speech, and found it to be present in every listener tested. This phenomenon was ascribed to outer ear resonance and the normal minimal audibility curve.
- (3) The SL at 1000 Hz was approximately 8 dB lower than the SLs at the peaks.

Quantification of Acoustic Cues From the Speech Spectrum

The Articulation Index (AI) was developed by communication engineers in 1940's, to assist in the design of telephone communication

systems in order to predict the percentage of intelligible speech signal perceived by a listener under various conditions of filtering, noise distortion, and low speech level (French & Steinberg, 1947; Kryter, 1962; Pavlovic & Studebaker, 1984). In order to quantify speech cues that influence intelligibility, French and Steinberg divided the overall bandwidth of a speech spectrum into 20 narrow bands that were adjacent to each other. Then, the speech was passed through various high-pass and low-pass filters and listeners repeated nonsense CVC syllables under test conditions that varied the level in each frequency band. Band importance and band weight were calculated for each frequency band based on the amount of contribution of each specific frequency region to the understanding of speech.

French and Steinberg (1947) found that a speech signal that has a long-term RMS SPL of -12 dB relative to the RMS level of white noise will be barely audible, the minimum contribution to the understanding of speech, and that the signal has a maximum in speech understanding at a signal-to-noise ratio (S/N) of not less than +18 dB SPL. In summary, they found that for the 30 dB dynamic range of speech, the percentage of available cues could be expressed between the values of 0.0 (no speech information available) to 1.0 (all speech information available). Although a linear relationship did not occur between dB increase/frequency band and AI, they concluded that the AI-value has a monotonic relationship to the word recognition score. That is, an increase in AI was proportional to an increase in word recognition.

In order to derive an accurate and precise computation for the AI, Pavlovic and Studebaker (1984) used the "Memphis Nonsense Syllable Test" to test the implications of various assumptions from the previous AI investigators. Using three normal hearing college students as subjects, actual word recognition performance was compared with performance predicted by the AI in 13 listening conditions. They found that a simplified AI using linear intensity weighting (dB/frequency band and AI) was accurate for listeners both in quiet and in noise conditions.

To summarize, the AI procedure, consisting of band importance and band weight components, has been used to quantify the percentage of available speech cues in English. Thus, its extensive application in hearing aid selection and fitting procedures fulfills the need to predict *a priori*, and for *post hoc* confirmation, whether a given hearing aid is benefiting the patient.

Summary

Differences in vowels in Australian and American English have been attributed to the variability between Byrne's data obtained from using Australian speakers and Cox and Moore's data derived from speakers of American English. In addition to the variability resulting from the linguistic differences, previous studies also revealed that speech spectra were influenced by the speech materials used. Seemingly, language or dialectal differences in a speech material may affect the resulting speech spectrum.

Due to the acoustic, phonetic, phonemic composition, pitch contour differences and subjective auditory perceptual distinctness between the

English and Mandarin, the concentration of formant energy may have a bearing on the average long-term speech spectrum of each respective language. Mandarin, therefore, was deliberately chosen for this comparative spectral study to determine if differences in the long-term RMS speech spectra exist between an intonational and a tonal language.

Figure 1. RMS speech spectra in 1/3 octave band levels.

CHAPTER III

METHOD

Introduction

This study was a controlled observation of performance measurement and analysis of generated speech spectrum of 20 adult native English speakers and 20 adult native Mandarin speakers. It was the purpose of this research to conduct a speech spectrum study with twenty English and twenty Chinese Mandarin dialect speakers in order to determine the spectral energy characteristics of the two languages and to make suggestions for hearing aid selection and evaluation techniques.

Subjects

Twenty English speakers (ten male and ten female) who acquired English as their first language and twenty Mandarin speakers (ten male and ten female) who acquired Mandarin as their first language and were proficient in the dialect served as subjects through volunteer solicitation among San Jose State University students, friends of this group and friends of the investigators. Ages ranged from 19-48 years with a mean age of 28 years for English speakers and from 20-37 with a mean age of 29 years for the Mandarin speakers. Any person who could not read aloud with reasonable fluency was excluded from the study. Speech samples were collected on two consecutive days.

Speech Material

As cited by Richards (1964), there are four assumptions regarding the differences between the speech production from reading speech material and natural conversational discourse: (1) pauses are compromised when

reading text, (2) speech sounds are uttered quite differently in reproducing written text as compared to that in a conversation, (3) different words may be used in writing and in conversation, and (4) a natural conversation is basically an interactive process between a participating listener and a speaker whereby the choice of words and methods of speaking are used accordingly. Although these differences exist, speech samples of the present study were collected by using reading speech materials.

The English speech material consisted of a 680-word short story selected from a magazine with a 6th grade reading level (Appendix A). The Chinese speech material, containing approximately 750 words, was a passage from a popular anthology of Chinese literature with an estimated reading level of 6th to 8th grade (Appendix B). The length of time required to read either passage was about 2.5 minutes.

The instructions given to the subjects were as follows:

"The nature of this experiment is to record a sample of fluent speech for a spectral analysis of ____ (English or Mandarin). The text is quite easy to read. It is about two and a half minutes long. I will ask you to read the text at a normal conversational level and normal speed. Please continue reading even if you realize you had made an error or omission. You may omit occasional words or phrases if you could not pronounce them. I will let you read the text silently before we start the recording. Understand? Do you have any questions?"

Recording Instrumentation and Procedures

A diagram of the recording instrumentation is given in Figure 2.

Figure 2. A diagram of the equipment used to record the speech samples for English and Mandarin.

Speech samples were recorded in the recording studio of the Music Department at San Jose State University. Ambient noise in the room was measured to be 40 dBA. Each subject was seated 2 feet (61 cm) from a dynamic uni-vocal microphone (ATM 63) which provided a relatively smooth peak free frequency response ranging from 50 to 17,000 Hz. The microphone was located at a 0^0 azimuth from the subject and was connected to a mixing board. A Quest Sound Level Meter (SLM) set on the linear scale was used to measure the vocal output at the microphone location. The speech samples were recorded onto a digital audio tape via a recorder (Tascam DA-30) with a flat frequency response. A 1000 Hz calibration tone measuring 65-dB SPL was recorded at the beginning of each tape to represent the peaks of speech. The subjects were given the reading instructions and began reading the passage, during which time the vocal output from the microphone was monitored via the vu (Volume Unit) meter of the digital tape recorder. Samples with large variation (± 5 dB) in vocal output were eliminated from the study.

Analysis

A diagram of the analysis equipment is given in Figure 3. The analysis

Figure 3. A diagram of the equipment used to analyze the recorded speech samples of English and Mandarin.

of the data was conducted in the acoustic laboratory at University of California, Los Angeles. The purpose of the analysis was to determine both the group long-term RMS levels of the collected speech samples, and the mean individual one-third octave band levels of the two languages. The recorded speech samples were replayed using a Sharp R-DAT Digital audio tape deck SX-D200. The output of the tape recorder was delivered to a B & K (Bruel & Kjaer) real time analyzer (Type 2033). A B & K Electronic Voltmeter (Type 2409) connected across the terminals of the real time analyzer monitored the input calibration and speech signals for replication purpose.

The B & K real time analyzer integrated the output level in 25 Hz wide bands every 100 msec over the frequency range from 100 to 10,000 Hz. In order to obtain the long-term RMS levels in the third octave bands, the voltage output of the analyzer was interfaced with a DEC LSI-II computer. A software program integrated the various energy levels at each

25-Hz point within specific preferred standard one-third octave bands. The output of the computer was then available as a hardcopy via a printer.

First, each subject's individual speech sample was replayed and delivered to the real-time analyzer and averaged to determine the individual long-term RMS levels in approximately 900 25-Hz wide sampling bands. Forty computer printouts of RMS dB level as a function of one-third octave band center frequency for each individual subject's speech sample were obtained.

Second, due to the sampling capability of the equipment, 64 sampling spectra were arbitrarily sliced from each speech sample and were replayed, delivered and cumulated into group data for each language for analysis. Two computer data printouts were obtained from the averaging.

Finally, the results were described in a relative manner re: the overall long-term RMS level of the speech by subtracting the group RMS level of each individual band from the group overall RMS level. The relative level was chosen to facilitate comparisons between the data and previous speech spectra from several sources (Cox & Moore, 1988; Pearsons et al., 1977). Using the group overall level, the relative level at each center frequency of third octave bands was then computed for each language. Thus, the shapes of the speech spectra were calculated without considering differences among speakers in overall level, since all speakers for each sample were "normalized" to the same overall speech level.

CHAPTER IV

RESULTS AND DISCUSSION

The individual subject data from the 20 English and 20 Mandarin speakers is in Appendix C and D, respectively. Here, the mean RMS level measured in each of the one-third octave band frequencies appears. The mean RMS levels (in dB SPL) for each one-third octave band, calculated by averaging the individual data and subtracting the values from the group overall RMS level, are given in Table 3.

The group overall RMS level for the English speakers was 93 dB SPL, and the corresponding level for the Mandarin speakers was 97 dB SPL. The relative data are shown graphically in Figure 4. Here, the group overall RMS is plotted as a function of one-third octave band center frequency for English (Series 1) and Mandarin (Series 2). As shown in the figure, the two spectra were similar in their overall shape and overlapped throughout the frequency range. In fact, the largest difference occurred at 2000 Hz, at which the difference was 4 dB.

An analysis of variance (two-way ANOVA; language x frequency) was conducted to determine if the differences between the two generated speech spectra were significantly different. The analysis is summarized in Table 4. The results revealed that no statistical differences existed between the English and Mandarin speech spectra ($F_{(1,40)}=0.582$; $p > 0.05$), i.e., the findings did not support the original hypothesis that significant difference between English and Mandarin speech spectra would occur.

Table 3

The Mean RMS Levels (in dB SPL) for One-Third Octave Band Center Frequencies for English and Mandarin

Frequency	English	Mandarin
99	21.70	20.20
125	19.00	16.60
157	7.25	8.05
198	6.54	7.55
250	4.90	5.65
315	12.70	12.05
397	9.95	9.05
500	7.55	8.50
630	7.95	9.80
794	10.10	11.35
1000	13.05	14.95
1260	12.25	15.90
1587	11.00	14.75
2000	12.45	17.10
2520	15.35	17.60
3175	15.15	16.40
4000	13.75	14.50
5040	13.95	16.30
6350	18.70	20.75
8000	22.55	24.30
10079	25.10	26.95

Table 4

The Analysis of Variance for the English and Mandarin Speech Spectrum

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between groups	1	17.941	17.941	0.582
Within groups	40	1233.625	30.841	
Total	41	1251.566		

Discussion

Results from this study revealed that although a 4-dB difference in the overall RMS level (Mandarin is louder than English) occurred, no statistically significant difference in mean overall RMS level of the two speech spectra occurred across the 21 one-third octave bands.

Recall that English and Mandarin were different in phonetic, phonemic composition and pitch contour. The differences were such that it was hypothesized that Mandarin might contain a higher concentration of low frequency energy and a wider range of high frequency energy than English.

This study has shown, however, that the vocal output for English and Mandarin, on the average, derived a similar spectrum configuration despite the fact that one is an intonational language and the other is a tonal language. It is hypothesized that this similarity between the spectra may be attributed to a mechanical "averaging effect" on the generated speech

samples whereby specific energy region differences in different languages were not accounted for.

Since known phonetic/phonemic and tonal and intonation differences between English and Mandarin do exist, perhaps other measurements such as the Articulation Index theory that reveal these differences would be more useful for inclusion in the hearing aid prescription formulas than the long-term speech spectrum. In this study, the energy in each frequency band, corresponding to band importance, can be calculated for Mandarin from the speech spectrum. The importance of the energy in each frequency band of Mandarin (band weight), however, has not been determined. Further research is indicated to determine the AI of Mandarin. The calculation of a Mandarin AI should be considered the "next step" for defining differences between Mandarin and English that could affect hearing aid fitting strategies for Mandarin speakers. AI predictions can be tested under various listening conditions of filtering, noise distortion, and low level speech by using lists of Chinese characters or syllables.

It is likely that the AI of Mandarin will be different from the AI of English for several reasons. First, the dynamic range of speech might be increased for Mandarin. This may be related to the 4-dB difference in the overall RMS level between the English and Mandarin speech spectra. The speech intelligibility of 0% to 100% must be based on an appropriate speech dynamic range; otherwise, the monotonicity principle will be violated.

Second, a non-linear intensity weighting may be necessary when calculating an AI in Mandarin simply because Mandarin is a tonal language. Thus, the tones affect the pitch pattern of each syllable and possibly affect the level. By employing a non-linear weighting approach, the contribution of level unit (dB) in the speech dynamic range that varies with frequency band can be measured with accuracy and precision.

Third, previous studies of AI predictions based on the English speech spectrum revealed that a smaller error between the predicted and observed scores was obtained when natural pauses were not included. In Mandarin, pauses must be considered when calculating the AI because the phonemic composition never ends with a consonant (other than vowels and the two nasal sounds). Thus, English speakers describe Mandarin as 'choppy' probably because the tones cause pauses between Mandarin words. Therefore, pauses between syllables/words or phrases are distinctive characteristic of tonal languages and must be taken into account. In contrast, the coarticulation and assimilation effects are much more prominent in the intonational languages.

Implication of Hearing-Aid Fittings. Based on the results and discussion, several implications for hearing-aid fittings may be made.

1. Since no significant difference between English and Mandarin speech spectrum was found, the long-term average speech spectrum of English probably can be use for Mandarin-speaking population in hearing aid evaluation.

2. Considering the dissimilarity between the two languages chosen for this study, yet derived two similar long-term average speech spectra, and

also considering that hearing aids amplify speech signals in a real-time manner, using a long-term average speech spectrum may not be adequate in defining the desired level/frequency relationship in hearing aid evaluation.

3. Perhaps the importance of each frequency region to the intelligibility of a given language, as described for English by the Articulation Index, must be known for each language in order to define the optimal hearing-aid fitting.

Figure 4. Generated long-term RMS levels for English and Mandarin

CHAPTER V

SUMMARY

Four research questions were proposed for the present study. They are answered as follows:

1. What are the spectral energy characteristics of Mandarin? No significant difference was found between the English and the Mandarin spectra even though Mandarin seems to have different energy concentration in different frequency regions as compared to that in English linguistically.

2. How does the spectrum of Mandarin differ from the spectrum of English? Results from the present study revealed no significant differences across the 21 one-third octave band frequencies for the two language. Four dB difference existed between the long-term overall RMS levels of the two languages (Mandarin louder than English), but both languages shared a similar spectral shape. A possible explanation for these results was that the long-term averaging procedure cancelled out the differences that are seen in short-term spectrographic studies.

3. What are the implications for optimizing the benefit if the English spectrum is used for Mandarin speakers in hearing aid fitting? Although the results of this study revealed no significant difference between the two speech spectra, further investigation is warranted to determine the influence of band importance and band weight in understanding speech signals between the two spectra.

4. Based on the generated data, what implications are suggested for hearing aid evaluation and fitting strategies with the Mandarin-speaking

population? The English speech spectrum can be used in fitting hearing aids for the Mandarin-speaking population. However, to determine the amount of understanding the perceived Mandarin speech signals in hearing aid evaluation may require further investigation in the Articulation Index Model.

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APPENDICES

Appendix A

ENGLISH SPEECH MATERIAL

It was spaghetti and meatball day at the Albert Einstein High School cafeteria. Jenny Lopez was halfway through her lunch when Sean Nolan slid into a seat across from her.

"Can I have a sip of your milk?" he asked.

"Can't you just buy your own? Here," she said angrily, passing him the pint carton. Sean was such a pain.

Jenny turned to chat with her friend Carol and a minute later, Sean returned the milk to her. "Do you want any more of my lunch?" said Jenny sarcastically, lifting the carton to her lips. As she drank, her shirt began to feel wet. She looked down and saw milk dribbling out of the carton and onto her shirt. Sean had punched a hole through the top of her milk carton!

Everyone at the table was laughing, even Carol. Sean was howling the loudest.

"I'll get you for this, Sean," said Jenny furiously. This made everyone laugh even louder. Jenny felt her face grow hot from embarrassment. She hated looking foolish.

"What's going on here?" It was Mr. Krupkie grabbed Sean by his arm.

As he was being led away, Sean said to Jenny, "You've got no sense of humor."

That evening, while Jenny was reading in her room, the doorbell rang. It was Sean. Jenny's mother let him in.

Crying Over Spilt Milk

Up in Jenny's room, Sean said, "Because you Can't take a joke, the principal gave me detention."

"I'm busy, why don't you leave?"

Sean took Jenny's time machine off her bureau, along with two universal translators. The time-traveling machine was Jenny's invention. The translators came from a trip the teens took to the 21st century. "Okay, I'll leave," said Sean with a mean chuckle. "And you're going with me."

Appendix A Cont.

ENGLISH SPEECH MATERIAL

He pressed the button on the machine, and the two teens disappeared from Jenny's house. In fact, they vanished from the 20th century.

A second later, Sean and Jenny found themselves in front of Notre Dame cathedral.

"We're in Paris!" exclaimed Jenny. "I've always wanted to go there."

Sean looked around and said, "Where's the Eiffel Tower?"

This wasn't the Paris they had seen in photos-it was much smaller, and was surrounded by a large stone wall. Beyond the wall sat castles on green hills. Sailboats floated down the Seine River. The streets were filled not with cars, but riders on horseback. And strangest of all, there wasn't a single TV antenna on any roof!

"Get a load of this sharp dude," said Sean. Approaching the teens was a man dressed in silk and velvet, with a feathered hat, and a dagger hanging from his belt. Sean stopped him and asked what year it was. The man seemed puzzled by the question. Of course! Sean wasn't wearing the universal translator. He popped it in his ear and asked the question again, and this time it came out in French. The man said, "I expect a foolish question from a person dressed so foolishly. This is the year 1564. As a matter of fact, today is New Year's Day!"

As the man continued on his way, Jenny observed, "Nice weather for January 1st."

"If I remember history class, nothing much happened in 1564," said Sean.

"And nothing much happens in your brain, either," shot back Jenny. "You've taken me into the past against my will-that's, that's timesnapping!"

"Oh, lighten up, Jenny," sighed Sean. Then he spotted some kids carrying books. "Let's hang out with them."

Sean was so unpredictable, he made Jenny nervous. She said, "Just don't forget that as a tourist in France, it's important to be polite."

One of the school kids came up to her: "I'm a poor student at the University of Paris. Please give me money to help pay for my logic and astrology lessons."

Appendix A Cont.

ENGLISH SPEECH MATERIAL

"I'm very sorry," Jenny said. "I don't have any money. But happy New Year anyway."

The students stared at Jenny, exchanged sly looks with each other and slowly walked around the corner.

Appendix B

CHINESE SPEECH MATERIAL

你知道你是誰？你認識自己嗎？

你瞭解自己在家庭及社會中所擔負的角色嗎？你是否在生活上常為做錯一件事而耿耿於懷，也會在自己軟弱時，抹殺自己的一切優點？

每個人一生中，通常都會同時擔任好幾種不同的角色。在家裡可能是兒子或女兒，兄弟或姊妹，但也同時是別人的父親或母親，叔叔或阿姨。你可能是公司的小職員，而又在夜間念書的學生。你也可能具有多方面的愛好，是合唱團團員、籃球隊員或是話劇演員。

你的性格由於生活背景及家庭環境的不同，先天後天的塑造影響，可能豪邁勇敢或小心謹慎，滿懷信心或畏懼怯懦，固執跋扈或溫馴解人。你的生活態度，可能野心勃勃或隨遇而安，心平氣和或急躁衝動，樂觀或悲觀，外向或內向。

你或許很獨立，肯信任別人，有宗教信仰，在任何環境或景況下，對自己都能有一個妥善的安排，生活上自得其樂的人；但你也可能是一個依賴心很重，喜歡猜疑，嫉妒小器，既不肯相信別人，也不肯相信自己的人。

很多時候，你可能非常誠實可靠，很具責任感，但偶而也不免想偷懶，佔別人一點小便宜。總之，你不可能十全十美，有時也會犯錯，這時，你必須重新檢討你的生活方針，做一番校正。

一個只關心自己的人，常貪婪地想要得到一切，竭盡所能的去索取，不顧別人的利益或感受，也因此往往將自己孤立起來，陷入迷惘、孤獨、憂鬱和沮喪之中，總以為全世界都將他遺棄了，不知道是他先關閉了自己的心門。

其實，每個人都有寂寞和孤獨的時候，但是千萬不要以最軟弱的時候，作為衡量自己的標準。對於已經失去的東西，不要再去追悔，但也同樣不可將自己陷於不切實際的空想中，諸如發橫財、一步登天等等。

錯誤發生時，要立刻設法挽救或彌補，千萬不可拖延，更不要設法遮掩，否則越陷越深，無法自拔。許多惡習就是在放縱自己、不予糾正的情形下逐漸養成的。俗話說「小洞不補，大洞難補」，正是這個道理。

怎麼樣認識自己，矯正缺點，發揮所長，使你的人生更臻於完善美好的境地。當你不斷追尋中，在你內心一定會感覺到，這個世界上仍有很多事值得盼望，值得努力，值得成長。

Appendix C

INDIVIDUAL DATA OF 20 ENGLISH SPEAKERS

	99	125	157	198	250	315	397	500	630	794	1000	1260	1587	2000	2520	3175	4000	5040	6350	8000	10079
1	11	5	1	8	4	5	3	0	4	10	8	8	12	11	11	11	9	11	14	18	19
2	5	5	3	1	1	11	8	8	7	11	12	10	9	14	12	17	15	20	21	25	28
3	25	27	6	2	3	19	10	11	7	6	11	14	10	9	16	14	12	12	14	17	19
4	28	27	5	2	1	10	8	6	8	8	10	13	11	9	16	13	11	10	13	20	18
5	36	34	8	5	3	14	11	5	2	4	7	8	6	8	13	12	13	14	20	25	27
6	33	31	11	4	0	14	9	5	7	9	12	10	8	12	10	12	7	8	13	24	27
7	29	22	1	1	3	13	9	9	6	7	10	14	9	9	14	12	12	14	17	20	24
8	11	9	6	7	7	10	8	6	6	8	13	14	11	14	14	16	12	16	19	20	28
9	24	21	1	2	3	11	7	7	6	6	12	13	13	11	16	17	9	10	15	20	23
10	37	35	10	8	5	14	15	10	8	6	8	10	9	8	13	12	14	16	22	22	22
11	12	10	8	7	8	11	9	4	5	10	12	8	8	10	13	14	15	11	17	23	26
12	34	33	14	10	7	15	8	5	5	8	14	11	7	5	12	14	13	12	20	21	24
13	23	11	4	11	13	9	9	4	6	13	18	10	7	14	16	16	18	7	25	27	28
14	34	32	10	7	6	19	14	13	14	11	11	12	12	14	15	14	13	14	17	21	21
15	18	13	11	12	9	14	12	12	10	12	22	14	12	16	16	13	14	14	19	23	28
16	12	10	13	11	7	15	9	9	12	17	18	22	17	19	22	22	23	26	27	30	35
17	31	30	8	4	3	11	11	11	11	10	9	9	13	15	19	15	12	13	16	17	19
18	10	7	7	10	6	10	10	6	8	12	13	11	13	15	17	20	16	15	22	26	28
19	10	11	7	4	6	15	15	10	10	16	18	16	18	20	19	20	16	17	19	23	27
20	11	7	11	13	3	14	14	10	17	18	23	18	15	16	23	19	21	19	24	29	31

Appendix D

INDIVIDUAL DATA OF 20 MANDARIN SPEAKERS

	99	125	157	198	250	315	397	500	630	794	1000	1260	1587	2000	2520	3175	4000	5040	6350	8000	10079
1	30	21	6	3	5	15	9	11	15	11	15	23	19	14	18	19	15	15	21	27	30
2	32	31	19	9	1	14	24	11	13	10	9	17	16	19	19	15	11	11	17	22	24
3	22	21	5	6	9	17	13	9	9	18	17	14	14	20	16	16	11	15	23	25	25
4	11	6	0	5	3	2	3	4	3	4	5	7	5	13	9	10	5	8	11	14	16
5	19	21	4	4	7	8	6	3	3	6	9	6	6	13	11	13	10	10	17	20	26
6	8	8	13	9	5	10	8	9	11	15	19	14	12	18	19	15	14	22	23	27	32
7	11	9	10	8	6	11	9	11	9	15	18	19	16	23	21	20	18	16	22	24	25
8	13	6	7	15	2	7	3	3	3	10	12	7	8	12	9	9	12	21	22	22	23
9	10	7	6	5	2	9	6	5	2	5	9	11	8	11	11	13	20	20	21	23	24
10	7	5	3	3	2	6	1	1	0	5	12	9	7	11	12	7	10	13	14	20	24
11	11	8	11	16	12	15	13	13	14	13	21	20	19	22	27	27	21	15	25	30	31
12	11	7	0	0	1	4	0	4	2	3	5	0	7	7	9	10	7	14	16	18	22
13	17	11	6	7	8	12	8	10	10	13	18	17	13	16	14	18	15	18	21	22	25
14	14	10	14	14	8	20	13	11	11	14	24	19	16	24	24	19	18	19	21	24	30
15	28	23	6	9	13	16	17	16	16	16	25	33	29	29	23	17	18	21	25	31	30
16	30	27	6	4	3	18	12	13	19	15	18	20	20	19	22	17	12	16	24	25	28
17	30	20	8	9	9	10	9	8	13	9	12	17	17	16	21	16	13	18	25	30	33
18	28	24	9	8	9	16	10	12	9	14	18	18	17	15	21	19	20	17	23	26	29
19	35	34	17	10	4	14	8	7	16	14	15	20	22	19	21	24	21	17	21	25	27
20	37	33	11	7	4	17	9	9	18	17	18	27	24	21	25	24	19	20	23	31	35