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I am submitting herewith a dissertation written by Cynthia A. McCormick entitled "Mismatch Negativity and P300 Evoked Response Potentials: Perception and Discrimination of /r/ and /l/ in Korean and English Listeners." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.



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**MISMATCH NEGATIVITY AND P300
EVOKED RESPONSE POTENTIALS:
PERCEPTION AND DISCRIMINATION OF /r/ AND /l/ IN
KOREAN AND ENGLISH LISTENERS**

A Dissertation Presented for the
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Cynthia A. McCormick
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DEDICATION

This dissertation is dedicated to my mother and father,

Deanne P. McCormick and William F. McCormick.

I would not have persevered and obtained this degree without you.

All the thanks in the world could not possibly be enough
for what you have done for me.

I love you both.

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ABSTRACT

This study used behavioral measures in conjunction with electrophysiological measures to study perception and discrimination of /r/ and // in native American-English and Korean listeners. MMN and P300 evoked response potentials (ERP) were obtained from 13 American-English subjects and 19 Korean subjects. The stimuli used to elicit the ERPs were:

Tape One: Odd Tones Variable ISI - tones randomized in an odd-ball paradigm with a 2.0 to 4.0 second variable interstimulus interval - used to produce a P300.

Tape Two: La80/Ra20 Steady ISI - /la/ and /ra/ syllables randomized in an odd-ball paradigm with a 2.0 second constant interstimulus interval - used to produce a MMN.

Tape Three: La20/Ra80 Steady ISI - /la/ and /ra/ syllables randomized in an odd-ball paradigm with a 2.0 second constant interstimulus interval (opposite of Tape Two) - used to produce a MMN.

Tape Four: La20/Ra80 Variable ISI - /la/ and /ra/ syllables randomized in an odd-ball paradigm with a 2.0 to 4.0 second variable interstimulus interval - used to produce a P300.

All subjects, English and Korean, were given two discrimination tasks (AB and ABX paradigm) along with the four

taped conditions. The Korean subjects were divided into "Proficient" and "Non-Proficient" speakers of English based on their ABX scores.

It was hypothesized that the P300s elicited by the tonal stimuli and the MMNs elicited by the syllables would reveal no differences in the latencies and amplitudes among the three groups. The P300s elicited by the syllables were, however, expected to reveal prolonged latencies and reduced amplitudes in the Non-Proficient Korean group due to the difficulties of perceiving /r/ and //, documented in native Korean listeners.

Statistical analyses using MANOVA, ANOVA, Pearson and Spearman Correlation procedures revealed (1) no significant differences in the latencies and amplitudes of the P300s generated by the tonal stimuli among the three groups, and (2) no significant differences in the latencies and amplitudes of the MMNs generated by the phonemic stimuli among the three groups.

Although graphed data appeared to reveal prolonged latencies in the P300s elicited by the syllables for the Non-Proficient Koreans, a one-way MANOVA indicated that there were no statistically significant differences in the latencies or amplitudes among the three groups. Because of this finding, no relationship between the behavioral measures and the electrophysiological measures was found to exist.

These findings could be a function of the relative English proficiency of these Korean subjects (too homogeneous), the result of the subjects making discriminations on an acoustic rather than

linguistic basis, and/or the result of a large degree of variability found in the groups' mean latencies and amplitudes.

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CHAPTER I

INTRODUCTION

Statement of the Problem

Speech Perception: In the 1950's, Chomsky (1957) proposed the theory that language learning is innate in humans and only has to be environmentally triggered. That is, a child simply has to hear a language in order for it to be learned. He later modified this theory, however, to state that language learning is intrinsic or inherent, and it is the language mechanism that is innate or inborn (Chomsky and Halle, 1968).

Similarly, some speech scientists believe that the perception of speech sounds is innate, the result of a special evolutionary adaptation or mechanism (Miller, 1981). These scientists argue that human beings are born with "detectors" for speech cues and that an innate predisposition enables children to learn language. Eimas, Siqueland, Jusczyk, and Vigorito (1971) reported that infants as young as one month of age "are not only responsive to speech sounds and able to make fine discriminations but are also perceiving speech sounds along the voicing continuum in a manner approximating categorical perception, the manner in which adults perceive these same sounds." The authors reported that infants are able to sort acoustic variations of adult phonemes into categories with little

exposure to speech, as well as essentially no experience in production of these sounds. The authors concluded that the means by which categorical perception is accomplished is possibly part of the biological makeup of humans, and that these means are active at a very early age.

Critics of this theory believe, however, that the detector might be acquired through learning because speakers of different languages select different features as significant (Searle, 1969; Aslin and Pisoni, 1980). Infants can discriminate contrasts that are not phonemic in the parental language and that are in fact difficult for adults of their linguistic community to perceive (Miller and Eimas, 1983). Languages differ both in which phonetic categories are used and in the location of the boundaries between categories. Therefore, Miller and Eimas (1983) state that the perceptual categories of the infant must undergo modification as they develop into the specific linguistic system of the parental language. Logan, Lively, and Pisoni (1991) stated that early experience with a particular language serves to modify the child's perceptual system so that only those phonetic contrasts that denote differences in meaning remain distinctive. Werker (1989) attributed the modifications that occur between infancy and adulthood to a language-based reorganization of the categories of communicative sounds, rather than a loss of auditory sensitivity.

Second Language Learners: Investigators of perception in second language learners have reported that adults do not perceive non-native phonetic contrasts as well as infants. That is, adults have difficulty perceiving contrasts that do not include phonetic variants similar to those found in their native language (Strange and Dittmann, 1984).

The exact relationship between production and perception is yet unknown and remains controversial. Investigators of studies using infants and young children have concluded that speech perception abilities precede speech production abilities (Strange and Broen, 1981). Investigators using adults learning a second language are not, however, as consistent with their conclusions. Some researchers have found that adults learning a second language can perceive contrasting phonemes even if they can not produce them (Cochrane, 1977; Neufeld, 1977). Other researchers have found that second language learners can produce certain phonemes in a native-like fashion, even when their perception skills are not native-like (Gass, 1984).

Non-Native Confusion of English /r/ and /l/: Jamieson and Morosan (1989) reported that speech sounds which are easily identified by native speakers of a language often remain confusing to speakers less familiar with the language. These perceptual difficulties are expected in persons with limited exposure to the language; however, some speech sounds seem to present difficulties

long after the new language has been learned. For example, the English phonemes /r/ and /l/ present difficulties for native Japanese and Korean speakers learning English as a second language (Goto, 1971; Miyawaki, Strange, Verbrugge, Jenkins, and Furimura, 1975; MacKain, Best and Strange, 1981; Mochizuki, 1981; Sheldon and Strange, 1982; Strange and Dittmann, 1984; Logan, Lively, and Pisoni, 1990; Takata, 1990; Schmidt, 1996). Findings in the literature suggest that for Japanese speakers, /r/ and /l/ do not have distinct phonemic categories. Few studies have used Korean subjects, although the Korean language does not have distinct phonemic categories for the English /r/ and /l/ either. That is, categorical perception of the /r/ and /l/, which is based on the recognition of a boundary that makes identification and discrimination possible, does not exist for Japanese and Korean speakers. The Japanese and Korean languages do not differentiate the English /r/ and /l/, and these speakers typically perceive these phones to be allophones of the same phoneme (MacKain, Best, and Strange, 1981).

Investigations of /r/ and /l/ : The majority of the investigators who have studied perception and production of /r/ and /l/ by Japanese subjects have used behavioral measures, in which the subjects would produce the phonemes independently, or in words, and were then judged on intelligibility by native speakers of American English (Goto, 1971). Other behavioral measures included

forced-choice identification and discrimination tasks (AB and ABX paradigms) (McGovern and Strange, 1977; Henly and Sheldon, 1986; Takata, 1990). More recently, investigators have used event related potentials (ERPs) to study perception and the /r-l/ distinction in Japanese and American-English subjects (Buchwald, Guthrie, Schwafel, Erwin, and Lancker, 1994; Walker, 1994; Kuykendale, 1995). Only one behavioral study using Korean subjects could be found in the literature (Schmidt, 1996).

Event-Related Potentials: ERPs have been used to study cortical waves in response to acoustic stimuli for many years (McPherson, 1996). ERP is a general term used to describe the many different electrical changes that occur in the brain when a sensory stimulus "evokes" a response. The ERPs that occur when the brain distinguishes one stimulus from another may provide an objective measurement of auditory discrimination (Picton, 1995).

One method of ERP recording is known as the "odd-ball paradigm," in which a series of stimuli containing both high-probability (standard) stimuli and low-probability (target or deviant) stimuli is presented to a subject. If the subject can discriminate electrophysiologically between the target and standard stimuli, a large complex of waves occurs in response to the target stimuli. The most prominent peaks in this complex are labeled N200 (a negative-going wave occurring around 200 ms) and P300 (a positive-going wave occurring around 300 ms).

The P300 wave is thought to result from cognitive processes related to relevant stimuli (Butcher, 1994), and some believe that it only occurs if the subject is actively engaged in the task of detecting (attending) the targets (Picton, 1992). Others believe that the P300 is also present in non-attending tasks of odd-ball paradigms. In this case, the amplitude of the P300 is a function of the value assigned to the task, and the latency is a function of the ease of discrimination of the task. Therefore, whether the task is attended or non-attended, the P300 is not necessarily an objective measure, yet it may be a dependable measure for determining if discrimination has occurred.

The mismatch negativity (MMN), at the N2 location, occurs whether or not the stimuli are attended; therefore, it appears to reflect the automatic detection of a "mismatch" between the target stimuli and some template or memory of the more numerous standard stimuli in an odd-ball paradigm (Picton, 1995). The MMN is present when the deviant stimuli are just discriminable from the standard stimuli, but not present when the difference is not perceptible. The MMN is therefore "a prime candidate for an objective neurophysiological test of auditory discrimination" (Picton, 1995). It would also stand to reason that the MMN is a prime candidate for an objective neurophysiological test of /r/ and /l/ phoneme categorization in adult Japanese and Korean listeners.

Event-Related Potential Studies: Buchwald, et al. (1994) used the P300 to investigate discrimination of minimal word pairs differing only in the /r/ and // phonemes with adult Japanese second language learners. Kuykendale (1995) looked at the relationship between fifteen Japanese speakers' electro-physiological and behavioral measures of perception and their "goodness" of production judgments (as judged by native American-English listeners) of the English phonemes /r/ and //. Walker (1994) explored the use of "the N200 and the P300 auditory evoked potentials in demonstrating both behavioral and neurophysiological evidence of any ambiguity in the perception of English prevocalic /r/ and // consonant phonemes by native Japanese speakers of English as a second language." None of these studies included Korean subjects. They also did not look at the MMN as a measure of perception or discrimination.

Rationale for the Present Study

Allophonic variations of a phoneme are not linguistically meaningful and are typically not perceived behaviorally. Native speakers of the Japanese and Korean languages treat the English /r/ and // as if they were allophones; therefore, they have difficulty recognizing the distinction between the two phonemes, as explained by many investigators (Mochizuki, 1981; Flege, 1988; Strange and Dittmann, 1984). Although behaviorally, native Japanese and Korean listeners may not distinguish between the English /r/ and //, there

is no reason to assume that they process the information differently from native English listeners. In fact, it is this investigator's belief that the neural mechanisms of the Asian group and American-English group are similar and, therefore, the two groups will physiologically process the acoustic information similarly. The only differences between the two groups may be seen in the latencies and amplitudes of the waveforms, since the r/l distinction is more difficult for the Asian listeners.

Some speech scientists believe that a listener must continue to be exposed to a language's phonemic contrasts in order not to lose the ability to perceive them (Burnham, 1986; Werker, 1989). The cause of this phenomenon is unclear at this time, with some believing that the loss is due to a lack of exposure to certain sounds in early infancy, and some believing loss is due to a redirection of attention by the development of a phonemic mode of processing around the age of formal language training. Whatever the cause may be, Burnham (1986) states that the sensorineural ability is maintained (neural responses remain intact), although the linguistic discrimination may be lost. That is, the ability to discriminate is not lost, but the distinctions are not linguistically relevant.

The MMN and P300 were used in the present study because the loss of perceptual ability with phonologically irrelevant contrasts is seen with adult native Japanese and Korean subjects, and because that loss is supposedly not a loss of sensorineural or physiological ability. The MMN and P300 are central measures of sensory function.

They may be used to measure the system's ability to discriminate acoustic contrasts essential for speech perception. The P300 component of the event related potential has been associated with informational value of the stimulus. It is, therefore, sensitive to the significance, or the categorical value, of the signal. These two measures may be helpful in explaining differences in speech perception among individuals with similar peripheral function, and they may also aid in understanding the neurophysiological pathways and mechanisms responsible for speech perception (Stokes, 1995).

Purpose of the Present Study

The purpose of this study was to use behavioral measures in conjunction with electrophysiological measures to study perception and discrimination of /ra/ and /la/ syllables in native Asian and American-English listeners. Specifically, behavioral measures (AB and ABX discrimination tasks) and the MMN and P300 event-related potentials were compared between Asian and American-English groups, to examine the relationship between behavioral and electrophysiological measures (amplitude and latency).

Research Questions

This study was designed to test the following questions:

1. Are there differences in the latencies and amplitudes of the P300s elicited by tonal stimuli among the Korean group

proficient in English, the Korean group not proficient in English, and the American-English group?

2. Are there differences in the MMNs elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group?

3. Are there differences in the latencies and amplitudes of the P300s elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group?

4. Is there a relationship between the behavioral test scores and the electrophysiological measures (amplitude, latency, and difference scores) for these subjects?

CHAPTER II

REVIEW OF LITERATURE

Speech Perception

Categorical Perception: The ability of a listener to detect stimulus differences across and within categories is known as categorical perception. Categorical perception is based on the recognition of a boundary, which makes identification and discrimination possible (Harnad, 1987). Each production of a speech sound (a phone) is slightly different acoustically from every other production. It is the language learner's task to decide which variations are allophonic (linguistically unimportant) and which variations are phonemic (linguistically important). For example, infants discriminate between a prevoiced and a simultaneously voiced stop. If the language surrounding these speech productions is Spanish, this discrimination is maintained. If the language surrounding the productions is English, prevoicing is not phonemic and the distinction is treated as linguistically unimportant. In terms of delayed voicing, the difference between a 10 ms delay and a 20 ms delay is within the category of "voiced" and, therefore, not perceived. However, the difference between a 20 ms delay and a 30 ms delay is perceived because this distinction crossed a categorical boundary. In speech, stimuli belonging to the same phonetic category are more difficult to discriminate than stimuli belonging

to different phonetic categories (stimuli on opposite sides of a phonetic boundary). This has obvious advantages for language processing. As Werker (1989) states it, categorical perception "allows a listener to segment the words he hears immediately according to the phonemic categories of his language and to ignore unessential variations within a category."

Infant Speech Perception: Eimas, et al. (1971) studied discrimination of synthetic speech sounds (the voiced and voiceless stop consonants /b/ and /p/) in one- and four-month old infants using a nonnutritive sucking (NNS) paradigm. The discriminability of the two synthetic speech sounds separated by a fixed difference in voice onset time was compared under two conditions: in the first condition, the two stimuli lay on opposite sides of the adult phonemic boundary, whereas in the second condition the two stimuli were from the same phonemic category. The authors reported finding that infants are able to sort acoustic variations of adult phonemes into categories with little exposure to speech, as well as essentially no experience in production of these sounds. The authors concluded that the means by which categorical perception is accomplished is possibly part of the biological makeup of humans, and that these means are present very early in life.

Miller and Eimas (1983) employed a two part experiment that addressed whether the prelinguistic perceptual categories of the infant, like the phonetic categories of the adult, are related to (1)

the fact that more than one acoustic property specifies a phonetic segment, and the value of one of the properties affects the manner in which the stimuli varying along another property are classified (a "perceptual trading relation") and, (2) contextual factors such as speaker, speaking rate, phonetic environment, and intonation contour. In the first experiment, these authors investigated the specification of a phonetic distinction by multiple acoustic properties, and in the second experiment, they examined the context-dependent nature of the acoustic properties that specify a phonetic distinction. Like Eimas, et al. (1971), these authors concluded that the manner in which the categorization of information for speech occurs was virtually identical in infant and adult listeners. Their findings indicated that the infant possesses finely tuned linguistically relevant perceptual abilities, which they attribute to aiding and shaping language acquisition.

Developmental Changes in Speech Perception: Werker (1989) has shown that within the first year of life, an infant begins to move from language-universal abilities to language-specific abilities that are characteristic of an adult. Language-universal refers to how infants are able to discriminate virtually any phonetic contrast used in a language, regardless of the environment in which they are raised, while language-specific abilities refer to the much more restricted abilities of mature adults to discriminate stimuli from phonetic categories not used in their native language. This

pattern of extensive infant capabilities and more limited capabilities in the adult lead to the suggestion that infants may have a biological predisposition to perceive all possible phonetic contrasts and that there is a decline in this universal phonetic sensitivity by adulthood as a function of acquiring a particular language (Werker, 1989).

The transition from language-universal to language-specific abilities appears to be a product of the interaction between innate perceptual mechanisms and early linguistic experience (Aslin and Pisoni, 1980). Lalonde and Werker (1995) designed a study for cross-language speech perception in infancy to determine if there is a relation between age-related changes in speech perception performance and other developing cognitive abilities. They studied forty 8- to 10-month old infants, the age at which approximately 50% of infants can still discriminate non-native phonetic distinctions (language-universal) and 50% have begun to act adult-like in that they can not discriminate non-native phonetic distinctions (universal-specific). They tested these infants using the conditioned, operant head-turn procedure (Task 1) to look at responses to change of phonetic categories within a series. The stimuli used were English voiced bilabial versus alveolar phones (/ba/ vs. /da/) and a non-English retroflex versus dental phonetic contrast of Hindi (/da/ vs. /Da/). These speech perception measures were used for comparison with visual categorization measures (Task 2) and object search measures (Task 3), both of which are non-

speech, cognitive tasks. This study was based on "the assumption that if the reorganization in speech perception is related to other developing cognitive/perceptual abilities, then some degree of synchrony should be obtained between the timing of the reorganization in speech perception and important developmental changes in other domains" (Lalonde and Werker, 1995). These authors concluded that changes in task performance occur simultaneously across all three tasks, and cognitive/perceptual competencies may have influences on developmental changes in speech perception by the time a child reaches one year of age.

The theoretical framework for conceptualizing the interaction between biological predisposition and environmental factors has three possible experiential influences: (1) experiences during a "sensitive period" may bring about development of an ability which is not yet expressed; (2) experience during this sensitive period may facilitate the rate of acquisition of an ability; and (3) when an ability is already present, experience may be necessary to maintain that ability. Studies with adults have indicated that listeners often have difficulty identifying or discriminating phonetic contrasts which are not used distinctively in their native language. This decline in speech perception capabilities would suggest that experience is necessary to maintain initial abilities. Eimas (1975) interpreted the pattern of change in perceptual development (which results when initial abilities are not maintained) as a result of

neural loss or atrophy of the cells most responsive to the non-native phonetic features.

Werker and Tees (1984) stated that it is theoretically possible "that a lack of linguistic experience may result in a decline in perceptual performance without being caused by neural atrophy."

Therefore, these authors designed a study to determine whether the decline in non-native speech perception represents a loss of sensorineural response capabilities, a change in attentional focus, or the use of language specific processing strategies. Eighty adult English-speaking subjects were used in four separate experiments. In Experiment 1, the subjects were tested on their ability to discriminate two non-English speech contrasts in a "category-change" discrimination task after first being predisposed to adopt one of four perceptual strategies. The subjects were instructed to make use of either (1) a native-language phonemic perceptual strategy, (2) an acoustic categorizing perceptual strategy, (3) a single-token phonetic perceptual strategy, or (4) a within-category vocalic perceptual strategy. In Experiments 2, 3 and 4, the subjects were tested in a "same/different" discrimination task. In these experiments, the investigators looked at the effects of limited training and duration of interstimulus interval on subjects' discrimination ability. The authors concluded that the age-related decline in cross-language speech perception performance is not the consequence of a neural loss. It is their belief that under some circumstances, adults discriminate speech sounds according to the

phonemic categories of their native language. Under other circumstances, adults discriminate the same sounds according to phonetically relevant category boundaries used in another language, not their native language.

The issue of loss versus relearning is important, yet still unresolved. Pisoni, Lively, and Logan (1994) believe that further studies are necessary to determine if the neural mechanisms have atrophied due to lack of stimulation during development, or if they are simply realigned and only temporarily modified due to changes in selective attention. These authors feel that the loss versus relearning issue stresses the importance of focusing on the beginning language user and the time course of learning. For this study's purposes, the loss versus relearning issue addresses the broader issues of neural flexibility or inflexibility. Are native speakers of foreign languages doomed to perceiving only their native, relevant contrasts, or will they be able to relearn non-relevant contrasts of different languages?

The Japanese and Korean Languages

Japanese is spoken by approximately 120 million people throughout Japan, Hawaii, and the North and South American mainlands (Miyagawa, 1990). It is also spoken as a second language by the Chinese and Korean people who were living under Japanese occupation at the beginning of this century. The Japanese language has an open-syllable sound pattern, so that most syllables end in a

vowel. There are five vowels, /a/, /i/, /u/, /e/, and /o/, in the modern Japanese language (eight vowels in Old Japanese). Vowel length often distinguishes words, as in /to/ for "door" and /too/ for "ten." The basic consonants are: /k/, /s/, /t/, /n/, /h/, /m/, /r/, /y/, /w/, and the syllabic nasal /N/. Unlike English, which has stress accent, Japanese has pitch accent. This means that after an accented syllable, the pitch falls. There are several dialects throughout the many islands of Japan. Some dialects spoken in the southern areas of Japan are virtually incomprehensible to the speakers of other dialects. Therefore, a standard (or "common") dialect has been developed and is used most often by the media (Miyagawa, 1990).

The Korean language is one of the world's three hardest languages to master. It is spoken by approximately 60 million people who live on the Korean Peninsula and its adjacent islands, and by more than 3 million people who live throughout the world (Yum, 1996). "Hangul" is the alphabet of the Korean language. It was "devised" by King Sejong, who wanted to create a unique alphabet that was suitable for all Korean people, regardless of class. Hangul consists of 24 characters, which represent pictures of the mouth as the sounds are spoken. These characters are equivalent to the Roman alphabet's 'G,' 'T,' 'M,' etc., but by themselves they represent nothing and can not be voiced. There have to be at least two Hangul characters to represent a sound. Unlike the five vowels of English and Japanese, there are ten vowels in Hangul (Yum, 1996).

Second Language Learning

Factors that play important roles in second language (L2) acquisition include: context in which the language is learned (work, school, social), motivation, word stress, vowel timing, vowel duration, consonant timing, and voice onset time, for example. The factors affecting L2 pronunciation are numerous and interconnected. They include cognitive, social, and psychological factors, as well as the sensory and motoric aspects of speech learning. It appears that prior linguistic knowledge of a second language is also important to perception and production (Flege, 1988).

Gass (1984) studied the acquisition of production and perception by 10 non-native adult speakers of English. She investigated varied voice onset times for initial /b/ and /p/ phonemes and was able to conclude that second language learner perception is fundamentally different from native language perception. In this instance, stop consonants were not perceived categorically by the subjects. Instead, they were perceived continuously. Gass stated that perception of the second language was influenced in subtle ways by both native language and target language phonemic boundaries.

Miyawaki, Strange, Verbrugge, Liberman, Jenkins, and Fujimura (1975) stated that Japanese university students who had never lived in an English-speaking environment were not able to discriminate synthetic /r/ and /l/ at better-than-chance levels. Discrimination of nonspeech stimuli, however, was virtually

identical for Japanese and American subjects. They concluded that the effect of linguistic experience is specific to perception in the "speech mode." Mochizuki (1981) also showed that Japanese learners with greater English L2 experience succeed better in perceiving the English /r/ and /l/ phonemes. All Japanese learners had a better chance of identifying /r/ and /l/ in initial positions of words, and the phoneme /r/ gave the Japanese subjects more difficulty, regardless of L2 experience, than the phoneme /l/. Mochizuki also noted that /w/ exists in the /r-l/ continuum for the Japanese subjects, but it did not for the English subjects.

English /r/ and /l/: Many languages of the world do not contain a contrast between the liquid /r/ and /l/ sounds (e.g., Japanese, Chinese, and Korean). Flege (1988) states that 77% of languages have some kind of /r/, usually a tongue-tip or uvular trill, a flap, or a tap produced with light contrast between the tongue tip and alveolar ridge, but only 8% of languages have an /r/ resembling the English /r/. The English /r/ is produced either by retroflexing the tongue tip, or lifting the mass of the tongue body towards the palate and simultaneously drawing the tip back into the body of the tongue (Flege, 1988). In contrast, the Japanese /r/ often sounds like /d/ to English listeners. It is typically a loose alveolar stop in initial position, or the so-called "flapped-r."

Only about 75% of languages have an /l/ - usually a voiced lateral formed with constriction in the alveolar region. But the

English /l/ is formed by making contact between the lateral margin(s) of the tongue, the teeth and gingiva (Flege, 1988).

An important acoustic difference distinguishing English /r/ and /l/ is the starting frequency of the third formant and its rate of transition into or out of an adjacent vowel sound (McGovern and Strange, 1977). Polka and Strange (1985) used synthetic versions of "rock" and "lock" to generate four temporal variations in each of ten stimuli of a spectral-cue continuum. Spectrographic analysis of the isolated /r/ (prevocalic location) revealed that the third formant (F3) frequency at onset is low, close to the second formant (F2) onset, and rises to the F3 frequency in the following vowel. For the isolated /l/ (prevocalic location), the F3 onset is high relative to the F2 onset. The F3 is usually at or above the frequency of the F3 in the following vowel. This makes the F3 fall slightly during transition. Polka and Strange (1985) summarize these characteristics by stating, "F2 onset frequencies for /r/ and /l/ are not very different and the ranges within which they vary across vocalic contexts overlaps. As a result, although F2 onset frequency is usually higher for /l/ than for /r/, this parameter alone does not reliably differentiate the phonemes across different contexts, although it may function as a redundant cue in certain environments. Onset frequencies of F1 are characteristically low and by themselves do not serve to differentiate the liquids."

Hay and Fukuzawa (1979) conducted spectrographic analyses on /r/ and /l/ in English CV syllables produced by four native American

English speakers and two native Japanese speakers learning English. They determined that the Japanese subjects produced /l/ with a higher starting third formant (F3) frequency than /r/. However, the differences in the starting F3 frequencies of the /r/ and /l/ produced by the Japanese subjects were much smaller than the differences in the starting F3 frequencies of /r/ and /l/ produced by the American English subjects (approximately 1000 Hz for Japanese subjects compared to approximately 2000 Hz for English subjects). As a result of this, the /r/ produced by the native Japanese speakers sometimes had values appropriate for /l/. In fact, the /r/ productions of the Japanese subjects were heard as /l/ more often than their /l/ productions were heard as /r/. In addition to these findings, Hay and Fukuzawa reported that the duration of the F3 steady-state portion of /r/ and /l/ produced by the Japanese speakers was almost equal, but the steady-state portion of the /l/ was typically longer than that of the /r/ when produced by the English speakers. Also, the Japanese subjects produced a smaller difference in F3 transition duration between /r/ and /l/ (81 ms versus 66 ms) than did the English subjects (71 ms versus 31 ms).

Confusion of /r/ and /l/: Many children learning languages with two liquids have difficulty mastering (perceiving or producing) the /r/ and/or /l/. These phonemes are usually obtained later in language acquisition, even for normally developing children, but the /r/ and /l/ tend to pose a special learning difficulty for children

whose general speech development is delayed (Strange and Broen, 1981). This is not to say that native Japanese and Korean speakers have developmentally delayed speech. Instead, it may help to explain why these speakers have difficulty learning these liquids.

In their study comparing Cantonese and Japanese speakers, Henly and Sheldon (1986) stated that English contains a phonemic distinction between /r/ and /l/, while Japanese has only one liquid phoneme, /r/. Flege (1988) believes the factor that may make the acquisition of liquids difficult is the wide range of acoustically different allophones that exist for /l/, and even more so for /r/. He states, "a relatively great amount of allophonic variation in the realization of a category probably has the effect of making acoustic cues (e.g., the starting frequency of F3) relatively difficult for learners to isolate and use in perceptual processing."

Evoked Potentials

An evoked potential (EP) refers to a series of electrical changes occurring in the peripheral and central nervous system, usually related to the sensory pathways (McPherson, 1996). When the sensory pathway in which these electrical changes are occurring is the auditory pathway, the EP is referred to as an auditory evoked potential (AEP).

AEPs are categorized into specific time-lines. The early time-line, which occurs in the brainstem and measures the ability of the hearing mechanism at that level, is known as the auditory brainstem

response (ABR). The ABR occurs approximately 0 to 10 milliseconds post stimulus onset. There are seven components in the ABR waveform labeled I to VII, with Wave V being the most robust.

The middle time-line, known as the middle latency response (MLR), originates in the midbrain and occurs approximately 10 to 50 milliseconds post stimulus onset. There are four components of interest in the MLR: Na, Pa, Nb, and Pb. Each positive voltage wave is labeled with an uppercase 'P,' and each negative voltage wave is labeled with an uppercase 'N.' The sequence of waves is denoted alphabetically in lowercase.

The third, or late, time-line is known as the long latency response (LLR) and occurs approximately 50 and 250 milliseconds post stimulus onset. The main components, and their characteristic latency values, are P1 (50-80 ms), N1 (100-150 ms), P2 (150-200 ms), and N2 (180-250 ms) (Hall, 1992).

Following the long latency potentials are the event-related potentials (ERPs), which occur between 200 and 600 milliseconds. McPherson (1996) states that there are four major components, or types, of ERPs that are "classified more on the basis of function than time." The most studied component is the P300 (also referred to as a cognitive evoked potential). The contingent negative variation (CNV) is the second component, and the N400 and P500 are components which appear to be related to language and linguistic features of speech.

Exogenous Versus Endogenous: The terms *exogenous* and *endogenous* can be used to differentiate ERPs from early and middle evoked potentials. Exogenous responses are directly dependent on stimulus characteristics and are independent of the subject attending to or processing the stimuli (Hall, 1992). Endogenous responses are dependent upon the contexts within which the stimuli are presented, as well as the psychological state of the subject (Butcher, 1994). Exogenous responses are dependent on the physical parameters of the stimuli and tend to be more stable. Endogenous responses are affected by changes in patient status, therefore, tend to be less stable. Endogenous potentials are thought to reflect higher level processing than are exogenous potentials.

There are conflicting reports in the literature concerning whether the LLR components are exogenous or endogenous. Butcher (1994) believes that the LLR consists of both exogenous and endogenous components. She states that the N1, P2, and N2 are exogenous components, while the P300 is endogenous. Not all sources agree that the P300 is an LLR (due to its latency), and some sources consider the N2 to be an ERP, similar to the P300 (Butcher, 1994; Hall, 1992; McPherson, 1996; Peterson, 1995).

For the purposes of this study, the mismatch negativity (at the N2 location) and the P300 are both considered to be endogenous because they are both caused by responses to internal events (i.e., perception and cognition). They will be referred to as event-related potentials throughout this study.

Electrode Placement: ERPs are usually recorded with surface electrodes placed on a subject's head in specified locations using the International 10-20 system (Jasper, 1958). This system was devised (1) to allow researchers from different laboratories to consistently locate recording sites over areas of the brain to facilitate comparison of records, (2) to make possible a more satisfactory communication system for results reported in the literature, and (3) to allow for identification of the same locations in infants, children, and adults, regardless of head size. Because the 10-20 system was originally introduced as guidelines for electroencephalography (EEG) recordings it identifies up to 21 electrode locations. "Anterior-posterior measurements are based upon the distance between the nasion and the inion over the vertex in the mid-line. Five points are then marked along this line, designated Frontal pole (Fp), Frontal (F), Central (C), Parietal (P), and Occipital (O). The first point (Fp) is 10 percent of the nasion-inion distance above the nasion; the second point (F) is 20 percent of this distance back from the point Fp, and so on in 20 percent steps back for the Central, Parietal, and Occipital midline points (hence the name 10-20 system)" (Jasper, 1958). Fewer than 21 electrode sites are needed to record ERPs. In fact, the minimum recording montage consists of at least three scalp locations (Fz, Cz, and Pz) referred to a distance reference (left earlobe, A1, and right earlobe, A2) and a ground location (usually the high forehead, Fpz) (Picton, 1992).

Odd-Ball Paradigm: ERPs, particularly the MMN and P300, are recorded using an "odd-ball" paradigm. The odd-ball paradigm involves the presentation of a random sequence of two (or more) different stimuli, one of which occurs less frequently than the other(s) (Butcher, 1994). The typical pattern of an odd-ball paradigm is 80% of one stimuli and 20% of another (although 85% and 15% are increasingly being used). The stimuli that occur less frequently are known as "deviant," "rare," or "infrequent." The subject is instructed to acknowledge the presence of the infrequent stimuli in an active paradigm. Acknowledgments can be in the form of mentally acknowledging the stimuli, silently counting the stimuli, pressing a button corresponding to the occurrence of the stimuli, or a combination of these tasks. In a passive paradigm, the subject is not required to make any behavioral responses. The response characteristics (amplitude and latency) are known to be affected (decreased and prolonged) by the response mode; however, presence of the P300 does not require active participation on the part of the subject.

Event-Related Potentials

Event-related potentials (ERPs), also known as auditory evoked potentials (AEPs) or evoked response potentials, are a means in which speech perception can be measured directly from a neuro-physiological response. ERPs are changes in brain electrical activity

that occur in response to internal events, such as perception or cognition, which are triggered externally by some sort of stimulus.

Mismatch Negativity: Mismatch Negativity (MMN) is the term that refers to an automatic cortical evoked potential that indicates the brain's detection of acoustic change. Kraus *et al.* (1995) defines it as being reflected by "the neurophysiologic processes that underlie auditory discrimination." The MMN reflects certain aspects of processing and sensory encoding that are usually associated with higher-level centers, yet it is relatively free from linguistic, cognitive, and attentional influence.

An odd-ball paradigm is used to elicit the MMN, and the interstimulus intervals are held constant (under 2000 msec) between stimuli. A "difference wave" appears at approximately 180 to 250 msec after the onset of the stimuli. It is a "clear negative deflection beginning during the N1 wave but peaking later" (Picton, 1995). This small negative deflection is superimposed on the waveform in the latency range of the P2-N2 wave. It is elicited by a rare stimulus against a homogenous stimulus background and is assumed to reflect a physical mismatch between the neuronal model formed by the standard stimuli and the sensory inflow caused by the deviant stimuli (Aaltonen, Niemi, Nyrke and Tuhkanen, 1987). The origin of the proposed two intracranial generators for the MMN is believed to be the auditory cortex and other frontal areas (Näätänen, 1995).

Näätänen (1995) states that the MMN indicates preperceptual detection of change, independent of attention. The MMN is sharply attenuated in the absence of attention, but it is not fully eliminated. In fact, Créspe (1995) reported that the MMN has been recorded during sleep and with anesthesia.

Näätänen (1995) discussed the "memory-trace formation." He stated that when a sound is presented, the subcortical and cortical afferent mechanisms "map" the stimulus features first - he termed this the "stimulus-determined activation pattern." This, in turn, is followed by trace formation, which is "the mapping of this stimulus-specific afferent pattern into the neural systems of sensory memory." The dimension of time is a critical aspect of these traces. Näätänen proposed a "temporal window of integration," which is an approximately 2000 msec period of time (the most recent past) in which all acoustic incidents are integrated in perception. Näätänen (1995) proposed that the functional significance of the trace formation process is perhaps not only to represent the present and immediate past (i.e., to act as memory), but, also to provide an updated sensory prediction of the immediate future. With a greater than 2000 millisecond interstimulus interval, the neural trace is expected to "fade."

Both adults and children show robust MMN. Comparison of the MMN in these two groups revealed no statistically significant differences in peak latency, duration, or onset-to-peak amplitude. Yet, children show a larger MMN, with the difference being most

apparent in the peak-to-offset amplitude and overall area (Kraus, *et al.*, 1995).

Csépe (1995) reported that the MMN, in contrast to other auditory evoked potential waves, develops very early. The MMN is present in infants, and has been documented in children from 6 years of age up to adults. Multiple studies point to the conclusion that the MMN (to frequency deviations) appears to be stable in children, and it resembles adult responses. Csépe stated that the latency of the MMN to frequency deviations does not differ between adults and children, but its amplitude is larger in all age groups of children.

The MMN can be obtained with not only changes in stimulus frequency and intensity, but also with different kinds of temporal stimulus changes: changes in stimulus duration, stimulus order, the order of segments in a spectrotemporal stimulus pattern, ISI duration, the direction of a frequency glide, or in a rhythmic stimulus pattern formed by several tones (Näätänen, 1995). Because very small acoustic differences produce an MMN, Kraus, *et al.* (1993) believe that the MMN is a neurophysiologic index of fine discrimination of acoustic features.

P300: The P300, or P3, is a parietocentral positivity that occurs when a subject detects an informative task-relevant stimulus (Picton, 1992). It is named "P300" because it is a positive voltage component which occurs between 250 and 600 milliseconds. It is also called "P3" because it is the third major positive peak in

the late sensory evoked potential. The P300 is said to originate at the level of the cortex, however, the precise generators are still unknown. Gordon, Rennie, and Collins (1990) reported that the source of the P300 is either the temporal cortex or the hippocampus. There is evidence of a subthalamic and medial geniculate origin, with other activity noted in the gyrus orbitalis, rostral thalamus, and anterior commissure (McPherson, 1996). In either case, the P300 is maximally recorded from the midline centroparietal regions during ERP recordings.

The latency and amplitude of the P300 are determined by (1) maturation factors and (2) the ease or difficulty of a task. Maturation of the P300 provides some insight into the ontogeny of the developing brain for cognitive and sensory brain systems. For example, the ABR (sensory, exogenous) is mature at approximately 60 months of age, whereas the P300 (cognitive, endogenous) is not mature until about 14 years of age (Buchwald, 1990). Pearce, Crowell, Tokioka, and Pacheco (1989) hypothesized that neurodevelopmental processes, such as increased myelination and dendritic arborization, may underlie latency changes seen in children. Courchesne (1978) tracked the latencies of the P300 response in children and adults and determined that response time decreases with age. He reported that the P300 waveform becomes "adult-like" in the mid-teens. Yet there appears to be an upper age limit, of approximately 40 years, at which latencies of the P300

begin to increase again (Polich and Starr,1984). Therefore, the latency of the P300 becomes longer with increases in adult age.

The amplitude of the P300 is also affected by maturation. Infants and young children appear to have, on the average, greater amplitudes than adults. This may be due, however, to "latency-variability" because if the waveforms for latency-variability are corrected prior to averaging, the age-related amplitude differences in the P300 are not seen (Picton, 1992).

When the discrimination task becomes difficult, the latency of the P300 becomes longer (Picton, 1984). Polich (1987) investigated P300s obtained with "easy" and "hard" auditory discriminations and concluded that processing difficulty affected the latency (and amplitude) of the P300s.

Amplitude of the P300 is also affected by the difficulty of the task. Using visual stimuli, Johnson and Donchin (1978) concluded that as pairs of stimuli become increasingly difficult to discriminate, "their feedback value decreases and this decrease is positively correlated with a decrease in P300 amplitude."

Polich (1986) investigated factors which could affect the morphological quality and latency of the P300. The factors that were chosen for this study stemmed from the application of the auditory discrimination task to cognitively disabled subjects. "Because such individuals demonstrate fluctuations in concentration, may not tolerate long recording session, and have difficulty maintaining a stable body posture, ERP measurement

situations were designed which would mimic some of these conditions in cognitively able individuals" (Polich, 1986). Experiment 1 looked at the effects of graded changes in subject attention to the eliciting stimuli. Subjects were instructed to (1) count the target tones, (2) ignore all tones by daydreaming or thinking about other things, and (3) read from a book and be prepared to answer questions about the text. Experiment 2 looked at the effects of changes in stimulus probability (5%, 10%, and 20%) in an active (tapping finger for target stimuli) and a passive condition (ignoring tones while lying down with eyes closed). Experiment 3 looked at active and passive tasks with eyes opened and closed during each task. The results of these experiments suggest that the amplitude of the P300 is affected by variables which influence the certainty of the discrimination between the standard and target stimuli. How conscientiously a listener engages in a task appears to be a primary factor governing P300 amplitude. However, fluctuation in attention did not significantly affect peak latency. Similarly, variations in target probability from 5% to 20% did not affect P3 latency. Comparison of eyes open to eyes closed showed no significant effects for either P300 amplitude or latency.

In addition to the factors listed above, P300 responses may be influenced by glucose levels in the bloodstream, time of day (circadian rhythm), gender differences, body temperature, dementia, and handedness of the subject (Geiser and Polich, 1990; Peterson, 1995; Picton, 1992)

Event-Related Potential Studies in Discrimination

Molfese, Burger-Judisch, and Hans (1991) used auditory evoked responses (AER) to study discrimination in newborn infants. They used 19 female and 19 male full-term infants matched in age, Apgar scores, and parent handedness (as determined by the Edinburgh Handedness Inventory (Oldfield, 1971)). The auditory stimuli used consisted of four CV syllables synthetically produced and varied in second formant consonant transition and formant structure. There were two formant structure versions of each of the syllables /bi/ and /gi/. These versions were labeled (1) sine wave formant (nonspeech), and (2) normal formant (speech), and they differed in the bandwidth frequencies of the three formants contained in the syllables. Results revealed differences between male and female infant waveforms. Two portions of the ERP, one near the beginning of the response and one near the end of the waveform, indicated that the girls responded differentially to the two consonant sounds. The females' ERP waveforms to the speech and nonspeech stimuli also revealed differences, which did not show up in the males' ERP waveforms. Amplitude differences were evident among the electrode sites with the temporal region differing from the combined frontal and parietal regions. This study also revealed a clear left hemisphere discrimination of the two consonants in the 210 ms

region of the ERP. The authors concluded that:

Male infants clearly responded differently from female infants to the assorted speech sounds, and these discrimination differences were centered around 210 milliseconds and 630 milliseconds. In all cases, the discrimination skills of the female infants appeared to be better than that observed for the male infants. (p. 193)

Aaltonen, Niemi, Nyrke, & Tuhkanen (1987) discussed two competing "traditions" (hypotheses) of the nature of speech perception: the psychoacoustic tradition and the phonetic tradition. There is a pretheoretical disagreement between these competing traditions. The psychoacoustic (auditory) tradition "assumes higher order cognitive constructs only when psychoacoustically based explanations are not plausible" (Aaltonen, et al., 1987, p.198). The phonetic (categorical perception) tradition contends that "a speech continuum is perceived categorically in terms of language-specific speakers (Aaltonen, et al., 1987, p. 198). The largest differences between these two traditions are the mutually exclusive methodologies - the psychoacoustic method prefers to investigate the early psychoacoustic processes in the auditory system with direct recordings of the auditory nerve activity, while the phonetic approach uses mostly the method of absolute identification of the stimuli, which of course, is affected by a number of cognitive processes with long latencies.

These authors studied nine adult native speakers of the Finnish language using synthesized exemplars of the Finnish /i/ - /y/ continuum (the two end-points and one intermediate boundary sound). The only difference between these synthesized syllables was the F2 frequency; F2 = 2500 Hz for /i/, F2 = 2100 Hz for the boundary, and F2 = 1800 Hz for /y/. An odd-ball paradigm using "attend" and "ignore" conditions was used to elicit a MMN with standard and deviant combinations of the pure vowels /i/, /y/, and the intermediate boundary (e.g., /i/ and /y/; boundary and /i/; /y/ and boundary; etc.). The results showed that the larger the F2 frequency difference was between the standard and the deviant, the earlier and more robust was the MMN. They found this to be true in both the attend and ignore conditions, which suggested the processes underlying the MMN were automatic.

In relating their findings back to the two traditions of speech perception, the authors pointed out that the MMN reflects a discrimination process common to all auditory processing. Consequently, in speech processing, listeners have continuous rather than categorical acoustic feature information. This theory opposes the phonetic (categorical perception) tradition because, "for theories of categorical perception to hold true, they not only have to demonstrate abrupt category boundaries, but also refute the possibility of continuous processing. It is the latter challenge which is not met" (Aaltonen, et al., 1987, p. 205). Aaltonen and colleagues concluded by stating that it is likely that both acoustic

(i.e., continuous) and phonetic (i.e., categorical) processing occurs in the perception of speech stimuli. They feel that categorical perception is reflected, not in the MMN, but rather in the P300.

Kraus, McGee, Micco, Sharma, Carrell, and Nicol (1993) used school-aged children to study the MMN. Ten children from 7 to 11 years of age listened to two synthesized variants of the voiced stop consonant /da/. (A small group of adults were also tested for comparison reasons.) The two stimuli differed in the onset frequency of the second and third formant transitions. The specific characteristics of the speech stimuli used in this MMN experiment were based on behavioral data obtained earlier. In the behavioral experiment, children and adults were asked to identify stimuli along a 9-item continuum by pressing a button corresponding to /da/ and /ga/. The stimuli used in the ERP study, although different in their second and third formant transitions, were both identified behaviorally as the phoneme /da/.

The stimuli were presented at one second steady interstimulus intervals, with a total of 1200 responses to the standard and 200 responses to the deviant stimuli. The children were instructed to watch videotaped movies or cartoons and to ignore the test stimuli. The ERPs were recorded from Fz/A2 with the forehead as ground.

The MMNs were identified visually as the relative negativity following N1. The MMN was considered to be present if the amplitude at the peak latency was significantly different from the amplitude at the onset or offset of the MMN. The difference wave

was computed by subtracting the individual grand average response to the standard stimuli from the response to the deviant stimuli.

Results indicated that an MMN was present in all ten subjects tested. There were no significant latency differences (peak latency or duration measures) found between the MMNs of the children and adults. However, the peak-to-offset amplitudes and MMN area measures were larger for the children than for the adults. Yet the most important findings revealed that the MMN could be obtained to stimuli which are classified as the same phoneme. It showed that, although others have reported that children do not discriminate fine acoustic differences in speech stimuli, the robust MMN in children is an indication that certain fine stimulus differences are processed neurophysiologically.

This same group of investigators (Sharma, Kraus, McGee, Carrell, and Nicol, 1993) looked at the MMN in six adults ranging from 23 to 29 years of age. Two pairs of stimuli were chosen to elicit the MMN: (1) two stimuli (known as the "within category condition") which were behaviorally identified within the same phonemic category - /da/, and (2) two stimuli (known as the "across categories condition") which were behaviorally identified across two phonemic categories - /da/ and /ga/.

The MMNs were recorded from Fz/A2 with the forehead as ground. The subjects were instructed to watch a video tape in a sound-shielded room during data collection. The MMNs were obtained and identified as previously described above (Kraus, et al., 1993).

The MMN was detectable in all of the subjects in both the within category condition and the across categories condition. Repeated measures *t* tests revealed that the latency and magnitude measures were not significantly different in the within and across category conditions. Therefore, the MMN was not only obtained with stimuli identified as the same phoneme (as was the case with the children studied in Kraus, et al, 1993), but these MMNs were not significantly different from the MMNs elicited by different phonemes. Thus, the authors concluded that the MMN "appears not to reflect a speech-specific mechanism such as a phonetic feature detector tuned to formant transitions. The speech signal as reflected by the MMN appears to be coded like any other non-speech auditory signal at a pre-attentive level" (Sharma, et al., 1993).

Buchwald, Guthrie, Schwafel, Erwin, and Van Lancker (1994) used behavioral and electrophysiological measures to study native Japanese adults between the ages of 29 and 46 years who could converse in, read, and write English with proficiency. This group was compared to a group of Americans, native to the United States and who spoke English as a first language. For electrophysiological recordings of the P300, an odd-ball paradigm using four different stimulus pairs was used: (1) two minimally contrasting CV syllables, /ba/ and /pa/, (2) a word pair, "rip/lip," (3) a linguistic-prosodic pair, "Bob! (exclamation, high falling intonation)/Bob? (question, low rising inflection), and (4) an affective-prosodic pair, "Bob (angry)/Bob (happy)."

The first behavioral measure was obtained by having the subjects push a response button for the rare stimuli, during P300 recordings. The averaged ERPs recorded at Cz were compared among subjects within each group using paired *t* tests to provide a group statistic reflecting latency intervals across which ERP amplitudes differed significantly between rare and frequent stimulus presentations.

For the second behavioral task, the subjects were presented with pairs of pictures that corresponded to the stimulus pairs and were instructed to put a mark under the picture that matched the stimulus they heard. The third behavioral task tested the subject's ability to discriminate between word pair beginning with /r/ or //l/. A printed list of minimal pairs (rip/lip, rice/lice, rain/lane, red/lead, rock/lock) was given to the subjects, and they were instructed to circle the word that was heard on each trial.

The results of this study indicated that the Japanese and American subjects performed equally well in all three behavioral tasks, except for the trials using /r/ and //l/ stimuli. In the first task when the subjects were instructed to press a button corresponding to the rare stimulus, all subjects' responses were highly accurate with one exception: the Japanese performance on the "rip/lip" stimulus pairs showed significantly more errors than the American group performance. The electrophysiological recordings revealed that the Japanese data showed no significant differences between the rare and frequent averaged waveforms produced either

by "lip" or by "rip." Other verbal stimuli, making up linguistic, linguistic-prosodic, and affective-prosodic contrasts, produced no significant differences between the groups, either behaviorally or electrophysiologically. The authors stated, "in contrast to the virtually nonexistent Japanese P3 evoked responses to the "rip/lip" stimuli, the 100 ms negative N1 and 200 ms positive P2 potentials, which precede the P3 in latency, were consistently produced" (Buchwald, et al., 1994, p. 612). These potentials do not require rare/frequent stimulus discrimination for their appearance - i.e., they are not endogenous. The normal appearance of N1 and P2 in response to all stimuli in all Japanese subjects indicated, indeed, that the /r/ and /l/ stimuli were being centrally processed. However, the acoustic differences between these stimuli were not differentiated by the P3 generating system of the Japanese group (Buchwald, et al., 1994).

Kuykendale (1995) investigated production data of Japanese speakers' /r/ and /l/ and compared them to perception data consisting of behavioral and electrophysiological measures. Fifteen Japanese subjects ranging from 19 to 29 years of age, having "minimal experience with spoken English," were judged on the "goodness" of their production of the syllables /ra/, /la/ and the minimal pairs "red/lead" and "brush/blush." Two different panels, consisting of ten subjects each, were used to judge the Japanese subjects' productions. The first panel of ten were instructed to use a rating scale from 0 to 100 to represent the continuum from "poor"

to "good." The second panel of ten were given a list of possible pairs and were asked to circle the word or syllable in the pair that they thought they heard. The two sets of production scores (the 100 point scaled scores and the percentage of correct production scores) were compared to the Japanese subjects' behavioral and electrophysiological perception scores obtained in a previous study by Hilton, McPherson, Walker, and Harris (1994). That electrophysiological perception data consisted of "the latency (ms) and amplitude (μ V) measurements of the P300 and N200 long latency averaged cortical auditory evoked potentials when /r/ was the rare stimulus and when // was the rare stimulus" (Kuykendale, 1994, p. 10). The electrophysiological data had a behavioral component included since the subjects were instructed to press a button on the rare stimuli. Therefore, the behavioral perception data consisted of the correct (button press on rare stimuli) and incorrect (no button press on rare stimuli) identifications of /r/ and //.

Results indicated that there were no significant differences between /r/ ratings and // ratings for the Japanese speakers as a group. There were also no significant differences between the percentage of correct production for /r/ or //. When the production and perception data were analyzed, there were no significant correlations between the goodness of production data and the behavioral perception data from Hilton, et al. (1994). The electrophysiological data of the responses from the Japanese subjects revealed that, according to increases noted in the latency

measures, they had difficulties perceptually processing the difference between the /r/ and /l/ phonemes.

In conclusion, the author stated that the investigation found no systematic relationship between the judged goodness of production and perception of the English phonemes /r/ and /l/ for this sample of Japanese adults. These findings support Sheldon and Strange (1982) and Fledge (1988), who claim that no relationship can be determined between production and perception abilities of the /r-l/ contrast in Japanese adults learning English as a second language.

Walker (1995) completed a follow-up investigation to the Hilton, et al., and Kuykendale studies, looking at N200 and P300 latency and amplitude data. Seventeen native Japanese speaking adults with "minimal experience with spoken English" were included in this study. Sixteen native English speakers were used as the control group.

The stimuli consisted of four digitized representative syllables of /ra/ and four digitized representative syllables of /la/. The odd-ball paradigm (80%/20%) was used, and the subjects were asked to respond to the odd stimuli by pressing a button. The behavioral responses were scored as either a "hit" (button press on rare stimulus), a "miss" (no button press on rare stimulus), a "correct response" (no button press on common stimulus) or a "false alarm" (button press on common stimulus).

For the behavioral responses, the probability of a correct response was greater for the American listeners than for the

Japanese listeners. That is, the American listeners consistently identified a greater percentage of hits and had consistently fewer false alarms than the Japanese listeners.

The electrophysiological grand average waveforms revealed a clearly observable decrease in the amplitude of the N200 and in increase in the latency of the P300 when the Japanese were compared to the American listeners. No significant difference was obtained between the groups for the N200 mean latencies or the P300 mean amplitudes.

This author concluded that the Japanese listeners were more prone to guess at distinguishing between the /ra/ and /la/ than were the American listeners on the behavioral tasks. The ERP findings "support the conclusion that the measured disparities between English /ra/ and /la/ identification in American versus Japanese adult listeners probably arise from increased task difficulty and perceptual confusion of apparently ambiguous acoustic events in the native Japanese listeners" (Walker, 1995, p.26).

Summary

The bulk of the studies reviewed have utilized behavioral indices as a basis for the authors' conclusions of Asian speakers responses to the English /r/ and /l/ phonemes. These behavioral devices have used identification tasks ("what sound did you hear?"), discrimination tasks (AB and ABX), and/or production tasks of words with the /r/ and /l/ phonemes in various contexts. Very few studies

were found which used neurophysiological (e.g., ERPs) means of measuring this discrimination, and none were found which utilized a non-attending neurophysiological measure (MMN). That is the purpose of the proposed study: to measure behavioral and neurophysiological responses of Asian subjects in their response to the English /r/ and /l/ phonemes. The assumption is that the non-attending neurophysiological response will not differ by degree of proficiency with the English language.

CHAPTER III

METHOD

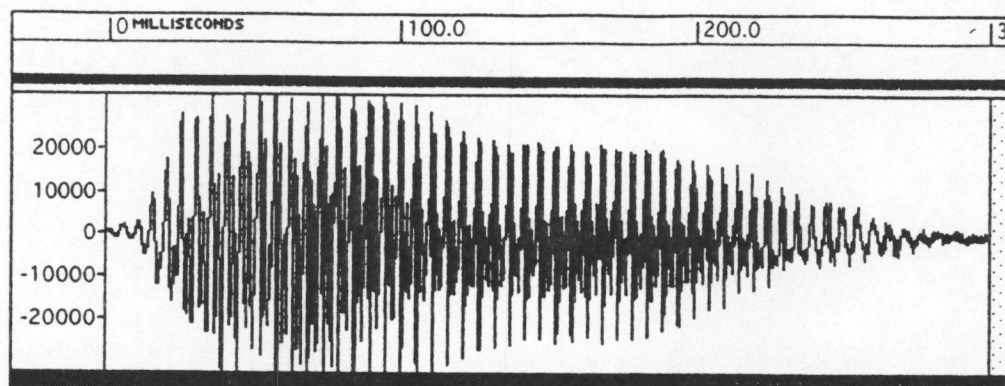
Subjects

The subjects used in this study were 19 adult native Korean speakers and 13 adult native American-English speakers, as determined by language history (Appendix A). The Korean speaking subjects were recruited for this study by placing notices (Appendix B) on bulletin boards at the International House, in the Asian Studies Department of McClung Tower, in Married Student Housing complexes, restaurants, and churches on and off campus, and the English Language Institutes of the University of Tennessee and Maryville College. The American-English speaking subjects consisted primarily of undergraduate students from the Department of Audiology and Speech Pathology at the University of Tennessee. The American-English subjects received extra-credit in departmental classes for study participation. The Korean subjects received a small monetary compensation for study participation.

Equipment

The speech stimuli (/ra/ and /la/) used in this study were digitized using a Sound Edit 16 computer program and stored on a Macintosh computer (Figure 1). After lists of 200 and 400 stimuli were generated, they were recorded from the computer onto Maxell

/RA/



/LA/

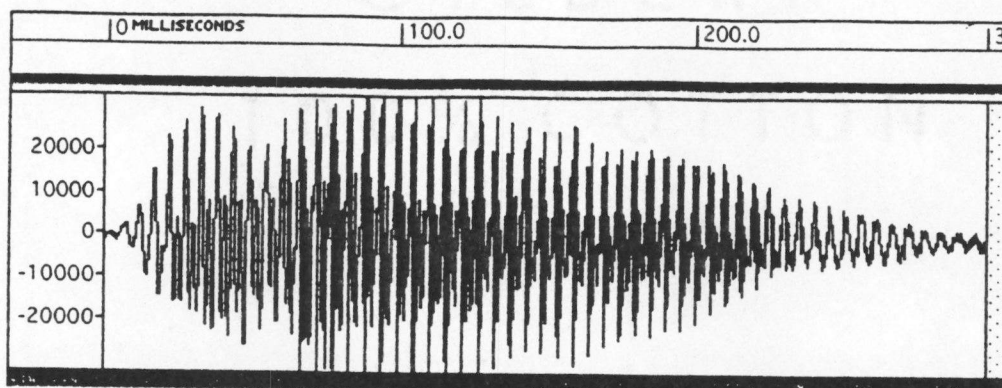


Figure 1. Waveforms of the stimuli produced by an American-English female speaker and digitized using a Sound Edit 16 computer program. The top waveform is /ra/ and the bottom waveform is /la/. Less energy is seen in the first 100 ms of the /la/ waveform.

UR normal bias standard audio cassettes with a JVC TD-W303 Stereo Double Cassette Deck (#115C3755).

The tapes for the AB and ABX discrimination behavioral tests were the same digitized stimuli as stated above; however, the presentation order was arranged differently. These stimuli were recorded on a TDK SD 90 high bias standard audio cassette and played to the subjects through an overhead Speco speaker (Model DMS-3PW) at approximately 70 dB A-scale (fast response) at ear level, as measured by a Realistic sound level meter (#33-2050).

A Panasonic Slim Line (Model RQ-2736, #ACJ9TBRQ-2738) tape recorder was used to record the speech samples of the Korean subjects, and each speech sample was recorded on a Sony HF normal bias standard audio cassette.

ERPs were recorded from 6 mm cup disk surface electrodes. Impedance readings were kept under 5000 Ohms, as measured with a Grass electrode impedance meter (Model EZM5A, #8031X7). The electrodes were connected to Grass P-511k cables (#F-P51C3) via protected receptacles (SAFELEAD F-E5 GH). The ERPs were fed through Grass Model P511 Preamplifiers, amplified 50,000 times, and passed through an analog-to-digital converter (MAB.56.6.8 Memory/Analog System, Benchtop Instrument compatible). Tektronix 2201 Digital Storage Oscilloscopes were used to display the unaveraged responses as a continuous monitor of subject activity. The Evoked Potential Analysis and Data Collection System (EPACS,

Version 1.1) was the software package used to display the formatted and averaged waveforms on a Macintosh SE personal computer.

The subjects were seated in a comfortable chair in the double-walled, sound-isolated room of the Neurolinguistics Laboratory of the Hearing and Speech Center for the AB and ABX behavioral tests, the speech sample recordings, and the ERP data collection with the EPACS. The ambient noise levels inside the sound-isolated room were obtained with a sound level meter (Bruel and Kjaer, Type 2226, #963765) and were determined to be under 23 dBA.

Subject Qualification Procedures

Each subject's native language was either American-English or Korean. Native language classification was based on the language spoken by the subject in the first five years of life. All subjects had normal hearing in at least one ear, as determined with pure-tone air conduction thresholds of ≤ 25 dB HL at 500, 1000, 2000, and 4000 Hz (ANSI, 1989). All subjects reported no known neurological, cognitive, or learning deficits (Appendix A).

Stimuli

The syllables /ra/ and /la/ were spoken by a female American-English speaker (the investigator), recorded and digitized through a Sound Edit 16 computer software program, and then stored on a Power Macintosh 6100/60AV. The Sound Edit 16 software allowed waveforms of the two syllables to be displayed and measured.

Modifications of the onset and offset of the syllables were made using cursors along the waveform display, and the modified syllables were played back acoustically. The durations of the /ra/ and /la/ were modified to be 300 ms. These durations allowed both syllables to be easily identified, as determined by four untrained, native American-English listeners. Interstimulus intervals (ISI) ranging from 2.0 to 4.0 seconds were placed between the syllables, depending on the ERP stimulus tape. Tapes One and Four had variable ISIs of 2.0, 2.5, 3.0, 3.5, and 4.0 seconds, while Tapes Two and Three had steady ISIs of 2.0 seconds.

Experimental Tests

Behavioral Tests: A tape of AB and ABX discrimination tasks was recorded for the behavioral tests in this study. The AB discrimination task consisted of 40 randomized presentations of /ra/ and /la/, and the subject was instructed to circle which syllable he/she heard. The ABX discrimination task consisted of 40 randomized presentations of sets of 3 syllables (i.e., ra-la-la, la-ra-la, ra-la-ra, or la-ra-ra). The subjects were instructed to circle the number "1" if the third syllable in the set sounded more like the first syllable, or the number "2" if the third syllable in the set sounded more like the second syllable. Therefore, the subjects were instructed to circle numbers rather than syllables. All subjects were seated in a comfortable chair in a sound-isolated room while performing these tests. The syllables were presented via the

overhead speaker at approximately 70 dB A-scale (fast response) at ear level, as measured by the Realistic sound level meter. The AB and ABX discrimination tasks are presented in Appendices C and D.

ERP Tests: Four tapes were recorded for the ERPs in this study. They were as follows:

Tape One: Odd Tones Variable ISI - a series of two hundred 1000 Hz (frequent) and 500 Hz (infrequent) tones randomized in an odd-ball paradigm (80%/20%) with a 2.0 to 4.0 second variable interstimulus interval. This tape was presented to each subject to establish a baseline P300 response.

Tape Two: La80/Ra20 Steady ISI - a series of 400 /la/ (frequent) and /ra/ (infrequent) syllables randomized in an odd-ball paradigm (80%/20%) with a 2.0 second constant interstimulus interval.

Tape Three: La20/Ra80 Steady ISI - a series of 400 /ra/ (frequent) and /la/ (infrequent) syllables randomized in an odd-ball paradigm (80%/20%) with a 2.0 second constant interstimulus interval.

Tape Four: La20/Ra80 Variable ISI - a series of 200 /ra/ (frequent) and /la/ (infrequent) syllables randomized in an odd-ball paradigm (80%/20%) with a 2.0 to 4.0 second variable interstimulus interval.

With the constant ISI tapes, contrasts between the syllables should generate both a MMN and a P300 because the memory trace formation described in the literature review (page 29) would not have time to fade. With the variable ISI tapes, a MMN is not expected (neural trace would fade), and the P300 should occur only if the subjects categorically discriminate between the pairs of syllables. Tapes Two and Three had the odd-ball paradigm reversed in an effort to control differences that might exist in the ERPs due to physical differences in the stimuli rather than differences due to condition. Stimuli were presented through an overhead speaker at approximately 70 dB A-scale (fast response).

Korean Speech Samples

In addition to the behavioral and ERP tests, each Korean-speaking subject was tape recorded (1) reading the "My Grandfather" passage (Appendix E), for an elicited speech sample, (2) answering short verbal questions, for a conversational speech sample, and (3) completing the "Pronunciation Test," for elicited speech samples of /r/ and /l/ in initial, medial, final, and blend positions of words (Appendix F). These speech samples were later evaluated by a panel of six native American-English speakers in order to help label the Korean subjects as "Proficient Speaker" or "Non-Proficient Speaker" of the English language. That is, the American-English speakers were told to rank each Korean speaker's speech sample on a scale of one (being least proficient) to ten (being most proficient). They

were also instructed to mark with an 'X' the incorrect pronunciations for each category on the "Pronunciation Test." The investigator then totaled the correct words for a percentage score (see Appendix G). Categorizing the Korean speakers into level of proficiency enabled the electrophysiological results to be correlated with behavioral test results and to the presence, absence, or delay of waveforms produced by experimental Tape Four.

Experimental Protocol

The first half-hour of each session was used to obtain the informed consent (Appendices H and I), identifying information (name, age, and gender), and to perform the qualifying procedures: hearing screening measurements, information about native language, and information on any known neuropathologies. During this portion of the session, the two behavioral discrimination tests were given to all subjects. The next hour to hour-and-a-half was used to obtain the speech samples from the Korean speaking subjects and perform the ERP testing, including electrode placement and clean-up time. These procedures were completed in a quasi-random order to eliminate any order effects.

All subjects had electrodes placed at F3, F4, Fz, Cz, P3, and P4 with linked ear references and forehead ground, according to the International 10-20 system (Jasper, 1958). The four experimental conditions (4 tapes) were presented in a quasi-random order. The two steady ISI tapes took approximately 10 minutes to complete,

and the two variable ISI tapes took approximately 12 minutes to complete. The subjects were given 3- to 5-minute breaks after every tape, while the unformatted digitized responses were converted to formatted responses.

In each experimental session, the subject was seated in a comfortable chair in a sound-isolated room. The tapes were played through an overhead speaker at approximately 70 dB A-scale (fast response) at ear level. To reduce muscle artifacts during data collection, the subjects were instructed to sit still, relax their face muscles, and blink as little as possible. Each subject was instructed to perform a task while listening to Tapes One and Four. For Tape One, the subjects were asked to push a button for the odd tones (low tones). For Tape Four, the subjects were asked to push a button every time they heard the odd phoneme (/la/). The subjects were instructed to quietly watch either a slide-show or video-tape during Tape Two and Tape Three. Background music was played at 50 dBA during the slides and video tape (S/N=20 dB). These various tasks and conditions were necessary to eliminate boredom and fatigue for the subjects and used in an attempt to obtain smooth ERP recordings. The investigator directly monitored five oscilloscopes and a television screen for subject movement. If large amounts of movement artifacts were identified on the oscilloscopes, the subject was reinstructed to remain still, and the averaging process continued or started over.

Experimental Responses

Averaged waveforms for the infrequent and frequent stimuli from each of the four tape conditions were visually inspected for the MMN and P300 components. Component identification and measurement was performed on the Fz and Cz locations. These locations were selected because the MMN is more readily identified in the frontal cortex (Fz) (Picton, 1995), and both the P300 and MMN are easier to identify at Cz because that location provides a greater amplitude of response (Peterson, 1995). Pilot study findings supported these locations as being the best for component identification and measurement.

The operational definition of the MMN was a relative negativity at N2 in the latency range of 180+ milliseconds. The operational definition of the P300 was the largest relative positivity which appeared later than 250 milliseconds after the stimulus onset. Because there is no standard method of measuring the amplitude of ERP components, amplitude measurements of the MMN and P300 were based on baseline-to-peak (BTP) measurements.

With the Odd Tones Variable ISI tape (Tape One), all subjects (Korean and American) were expected to show a P300 with latencies between 250 ms and 450 ms. With the La80/Ra20 Steady ISI tape (Tape Two) and La20/Ra80 Steady ISI tape (Tape Three), all subjects were expected to have an MMN with normal latencies between 190 ms and 390 ms. As with Tape One, the stimuli from the La20/Ra80 Variable ISI tape (Tape Four) were expected to elicit a P300 from all

subjects, but the latencies were expected to vary depending on the speaker's proficiency with /ra/ and /la/. The American-English listeners and the English-Proficient Korean listeners were expected to show earlier P300 latencies with relatively greater amplitude than the Non-English Proficient Korean listeners.

Statistical Analyses

Correlational Analysis: Because the scores were normally distributed for all measures except the AB behavioral task, a Pearson Correlation matrix was used to determine if there was a relationship between the behavioral test scores and the electrophysiological measures of these subjects. A Spearman Correlation matrix was used with the AB task.

Further Analyses: A one-way multivariate analysis of variance (MANOVA) was used as an overall multivariate test of significance to control the experiment-wise error rate. Even though significance was not identified, a one-way analysis of variance (ANOVA) was also computed to give the reader a better understanding of the experiment-wise error rate.

CHAPTER IV

RESULTS

Description of Subjects

American-English Subjects: A total of 13 American-English subjects (nine females and four males) participated in this study. They ranged in age from 20 to 39 years, with an average age of 24 years. All subjects spoke English as their primary language, and all subjects (excluding E1) had resided in the United States since birth (Appendix A).

Korean Subjects: A total of 19 Korean subjects (ten females and nine males) participated in this study. They ranged in age from 20 to 33 years, with an average age of 26 years. All subjects spoke Korean as their primary language; however, all subjects reported that they had studied English while living in Korea. Their years of English study ranged from five years to ten years, with a mode of eight years.

These subjects had various reasons for moving to the United States and for learning the English language: some had come for undergraduate and graduate education, some had been transferred with American husbands in the military, and some had come specifically to study English in the English Language Institute. Their length of stay in the United States ranged from 2.5 months to 84

months (seven years). The American-English and Korean subjects' raw data are shown in Appendices J and K.

Behavioral Tasks

American-English Listeners: Each subject, regardless of primary language, was given an AB and ABX discrimination task with 40 items each (refer to METHODS). All thirteen of the American-English listeners obtained 40 out of 40 (100%) of the /ra/ and /la/ syllables in the AB task. For the ABX task, the American-English listeners ranged from 70% to 100% correct, with a mean of 95% correct (Figure 2).

Korean Listeners: As anticipated, the Korean listeners had more difficulty with the AB and ABX tasks. Their scores ranged from 70% to 100% correct on the AB task, which gave an average of 92% correct. Only six of the nineteen subjects got all 40 syllables correct. The scores on the ABX task ranged from 53% to 100% correct, with an average of 81%.

When the Korean group was separated into "Proficient" and "Non-Proficient," the Proficient listeners obtained, on average, 95.6% on the AB task and 89.9% on the ABX task. The Non-Proficient listeners obtained only 86.5% on the AB task and 68% on the ABX task (Figure 2). Classification of "Proficient" and "Non-Proficient" can be seen in Appendix K.

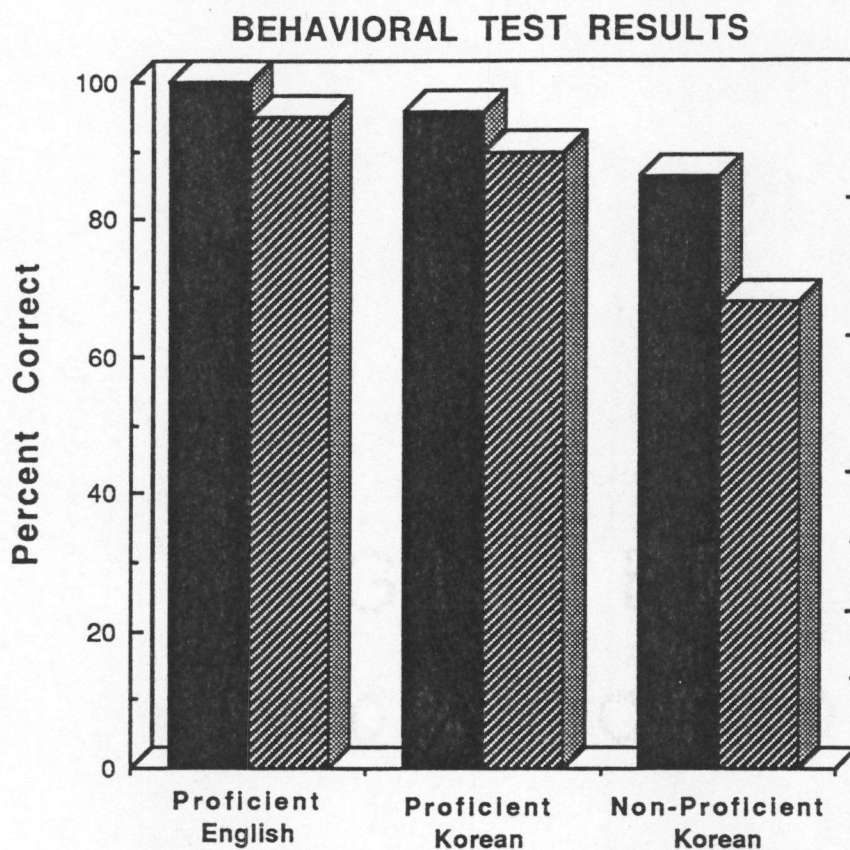


Figure 2. The averaged results of the AB (solid bar) and ABX (striped bar) behavioral tasks for the three groups. The Proficient English group obtained 100% and 95.0%; the Proficient Korean group obtained 95.6% and 89.9%; and the Non-Proficient Korean group obtained 86.5% and 68.0% for the two tasks, respectively.

Proficiency Labeling

The two behavioral tasks (AB and ABX) and the three speech samples were analyzed to determine which scores would best label the Korean subjects as "Proficient" or "Non-Proficient" in English. Each subject received a score (average of the six judges' scores) for the "Grandfather Passage," conversational speech sample, and the "Pronunciation Test." The number of correct responses out of 40 were used to obtain a percentage score for the AB and ABX tasks.

The scores given by the judges tended to group around the middle ranges. That is, many of the subjects received scores of "4," "5," "6," and "7," while only a small number received lower or higher numbers. (Figure 3 shows this phenomenon with the judges' scores for the Interview Questions.) As a result, the three speech samples were not used to determine whether a subject was proficient or non-proficient. The ABX task was determined to be the best indicator of Korean subject proficiency and was, therefore, used to separate the Korean subjects into groups of eleven Proficient Koreans and eight Non-Proficient Koreans.

Representative Waveforms

Examples of P300 waveforms obtained with Tapes One (Odd Tones Variable Interstimulus Interval) and Four (La20/Ra80 Variable Interstimulus Interval) are shown in Figures 4 and 5. The same subject's MMN waveforms obtained with Tapes Two (La80/Ra20 Steady Interstimulus Interval) and Three (La20/Ra80 Steady

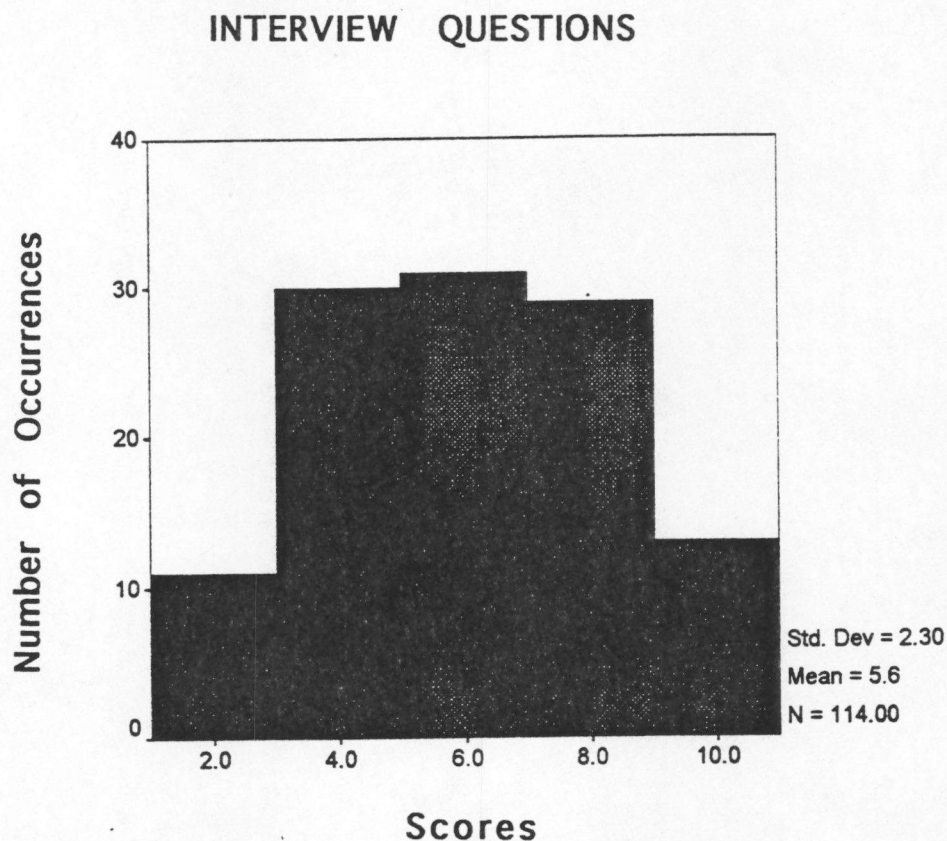


Figure 3. A histogram showing that the six judges' scores for the Interview Questions clustered or grouped around the middle range (i.e., 4, 6, and 8) of the judging scale. Therefore, the speech samples obtained from the Korean subjects were not useful for the determination of proficiency ratings.

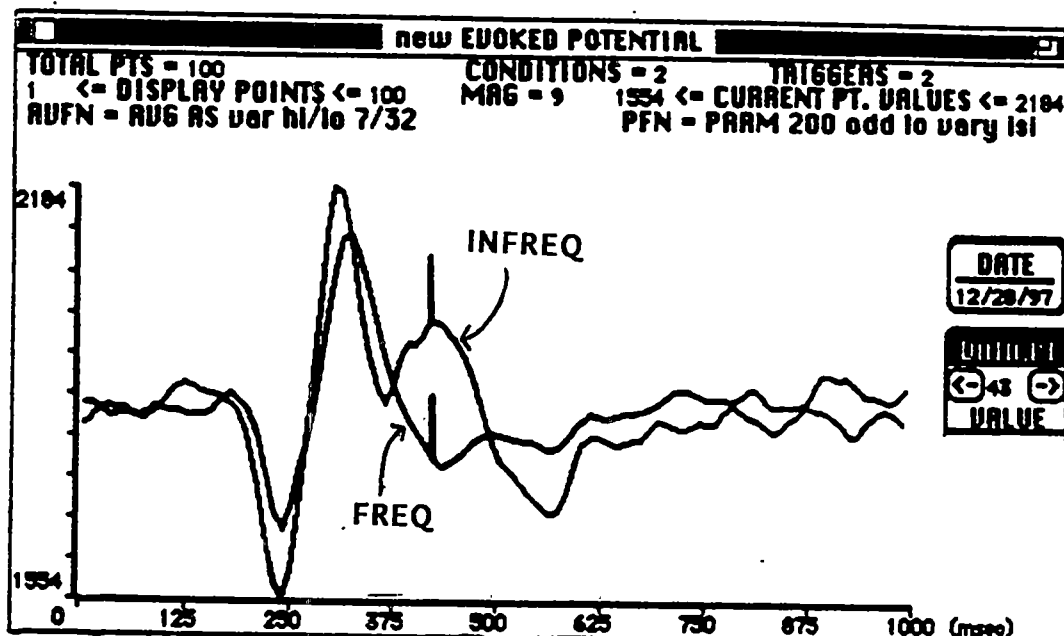


Figure 4. An example of the P300 waveforms obtained with the tonal stimuli of Tape One (Odd Tones Variable Interstimulus Interval). This P300 was obtained from Subject E9. The latency of the P300 was 330 ms. The amplitudes were 1981 μ V for the infrequent waveform (INFREQ) and 1764 μ V for the frequent waveform (FREQ).

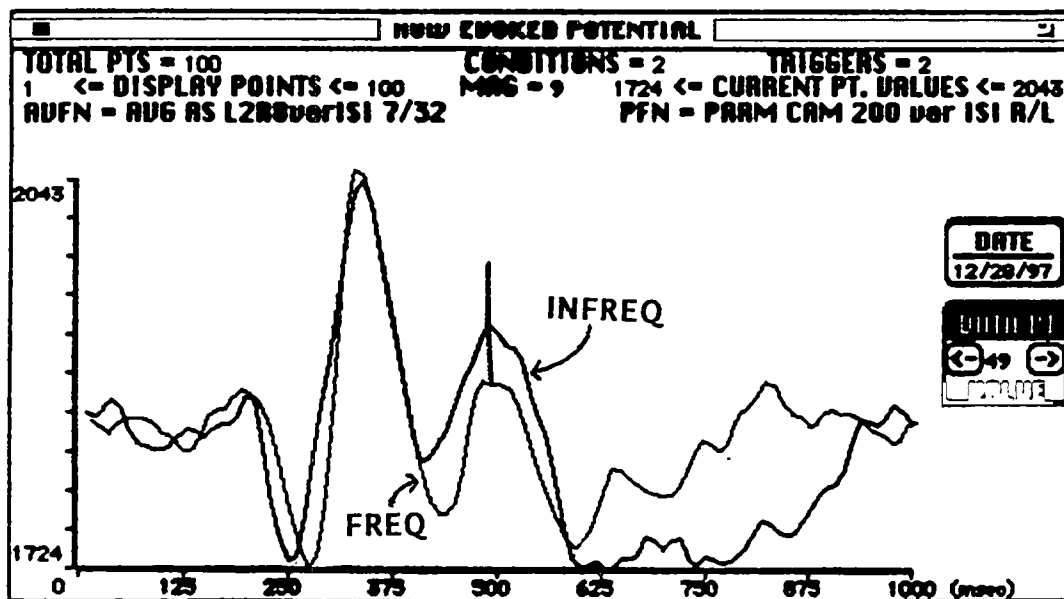


Figure 5. An example of the P300 waveforms obtained with the /r/ and /l/ phonemic stimuli of Tape Four (La20/Ra80 Variable Interstimulus Interval). This P300 was obtained from Subject E9. The latency of the P300 was 390 ms. The amplitudes were 1924 μ V for the infrequent waveform (INFREQ) and 1870 μ V for the frequent waveform (FREQ).

Interstimulus Interval) are shown in Figures 6 and 7. Not every subject produced waveforms with good morphology; therefore, if the infrequent waveform in the location of the P300 was not larger than the frequent waveform in the location of the P300, then a P300 was not labeled and an empty cell was put into the data set. Likewise, if the peak amplitude of the infrequent waveform in the N2 location was not less than the peak amplitude of the frequent waveform, then a MMN was not labeled and an empty cell was put into the data set (Figure 8).

Odd Tones Variable Interstimulus Interval

Tape One (Odd Tones Variable ISI) was used to determine if there were differences in the latencies and amplitudes of the P300s elicited by tonal stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group. With Tape One, all subjects, regardless of primary language, were expected to show a P300 with latencies between 250 ms and 450 ms. This was expected because tones should have equal meaning to each subject, whether his/her primary language is Korean or English. The task should be no more difficult for the Koreans than for the Americans. Therefore, the English listeners and the Korean listeners were expected to have P300 responses equal in latency and amplitude.

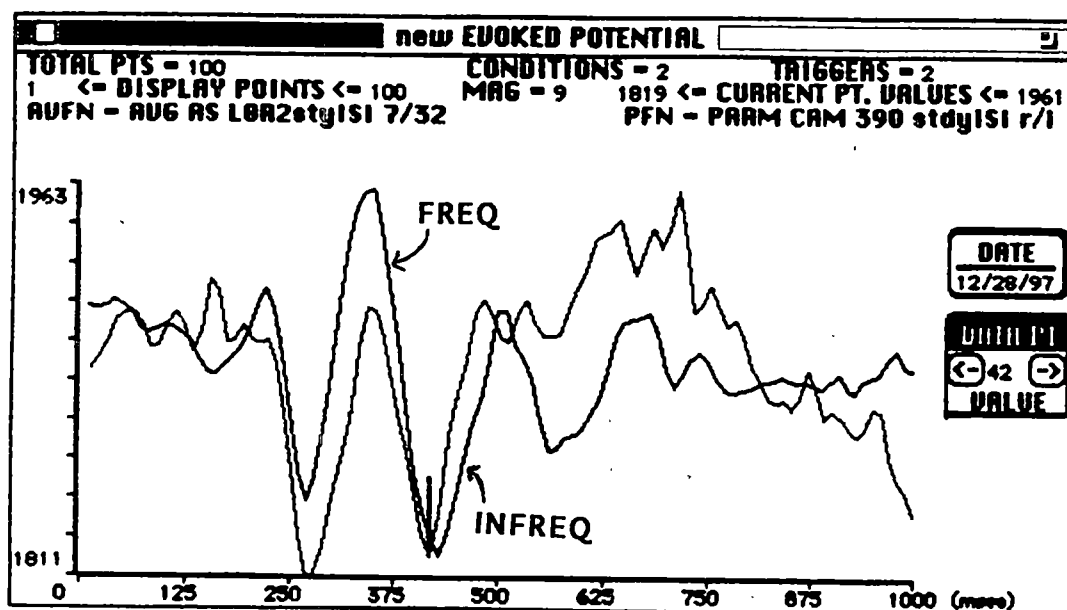


Figure 6. An example of the MMN waveforms obtained with the /r/ and /l/ phonemic stimuli of Tape Two (La80/Ra20 Steady Interstimulus Interval). This MMN was obtained from Subject E9. The latency of the MMN was 320 ms. The amplitudes were 1820 μ V for the infrequent waveform (INFREQ) and 1825 μ V for the frequent waveform (FREQ).

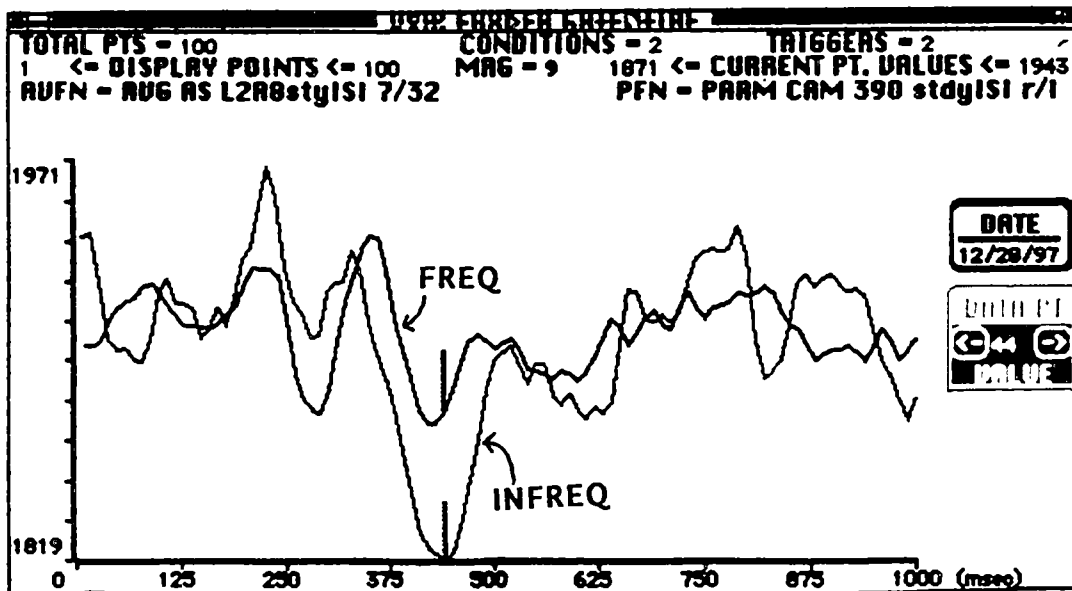


Figure 7. An example of the MMN waveforms obtained with the /r/ and /l/ phonemic stimuli of Tape Three (La20/Ra80 Steady Interstimulus Interval). This MMN was obtained from Subject E9. The latency of the MMN was 340 ms. The amplitudes were 1819 μ V for the infrequent waveform (INFREQ) and 1875 μ V for the frequent waveform (FREQ).

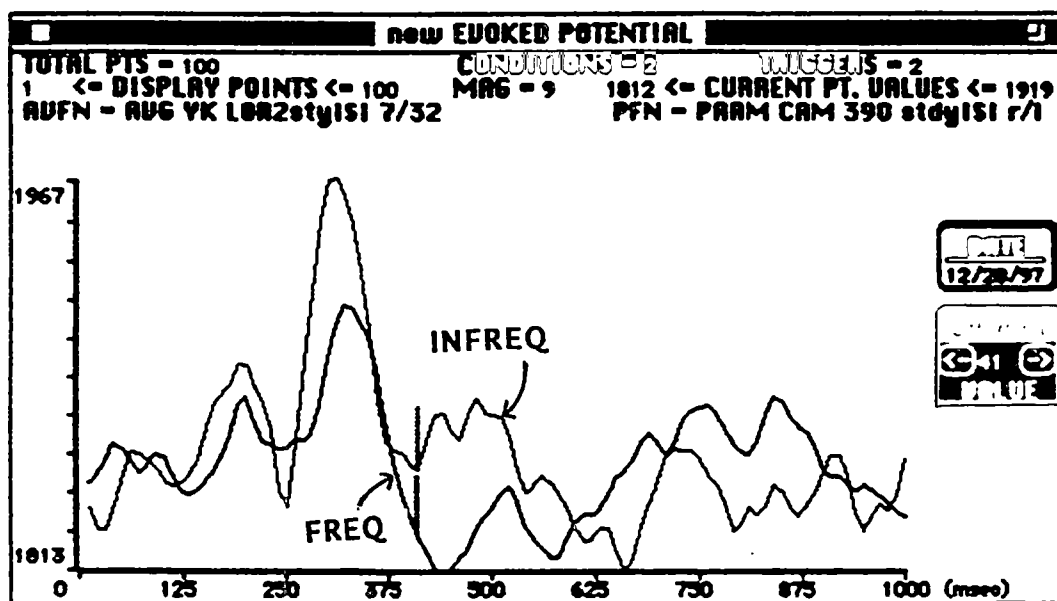


Figure 8. An example of waveforms obtained with the /r/ and /l/ phonemic stimuli of Tape Two (La80/Ra20 Steady Interstimulus Interval) in which the peak amplitude of the infrequent wave (INFREQ) was not less than the peak amplitude of the frequent wave (FREQ). With this type of response, an MMN was not labeled and an empty cell was put into the data set.

Because the data obtained in this study were grouped into the related categories ("threepro") of "American-English Proficient," "Proficient Korean," and "Non-Proficient Korean" a one-way multivariate analysis of variance (MANOVA) was used as an overall multivariate test of significance to control the experiment-wise error rate. Data were recorded (P300 present) from eleven American-English Proficient subjects, five Proficient Korean subjects, and seven Non-Proficient Korean subjects. The means and standard deviations for the P300 latencies, amplitudes, and difference scores can be seen in Table 1.

The MANOVA yields an omnibus, multivariate F test, also known as Wilks' Lambda. This F test indicates if one or more of the proficiency groups is significantly different from the others. The Wilks' Lambda reported for this MANOVA indicated that there was not a significant difference among the three groups ($F(6,36) = .603$; $p = .726$). Therefore, it was determined that there were no differences in the latencies and amplitudes of the P300s elicited by tonal stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group. The English listeners and the Korean listeners had the expected P300 responses, equal in latency and amplitude. Because of this finding with the MANOVA, no further statistical analyses were necessary; however, a univariate analysis of variance (ANOVA) table can be seen in Table 2 to demonstrate that not even the Bonferroni approach would find significance.

Table 1

Descriptive Statistics Table for the P300 Elicited by the Odd Tones Variable Interstimulus Interval Tape (Tape One)

	Proficiency	Mean	sd	N
LATENCY	Prof. English	357.27	21.5	11
	Prof. Korean	370.00	12.3	5
	NonProf. Korean	360.00	20.0	7
INFREQUENT AMPLITUDE	Prof. English	1943.5	70.8	11
	Prof. Korean	1907.8	46.9	5
	NonProf. Korean	1935.2	59.9	7
AMPLITUDE DIFFERENCE	Prof. English	135.8	59.3	11
	Prof. Korean	81.2	59.6	5
	NonProf. Korean	99.3	73.9	7

Note. Means, standard deviations, and number of subjects from which the latencies, amplitudes of the infrequent waveform, and the amplitude differences between the infrequent and frequent waveforms were recorded.

Table 2

Univariate ANOVA Tables for the P300 Elicited by Tape One

Source	Type III SS	df	Mean Square	F Value	Pr > F (p)
GROUP LATENCY ERROR	564.427 7618.18	2 20	282.213 380.909	.741	.489
GROUP AMPLITUDE ERROR	4408.92 80550.4	2 20	2204.460 4027.519	.547	.587
GROUP AMP DIFF ERROR	11825.24 82188.41	2 20	5912.621 4109.421	1.439	.261

Note: These ANOVA tables support MANOVA results indicating that there were no differences in the latencies and amplitudes of the P300s elicited by tonal stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group.

La80/Ra20 and La20/Ra80 Steady Interstimulus Interval

Tape Two (La80/Ra20 Steady ISI) and Tape Three (La20/Ra80 Steady ISI) were used to determine if there were differences in the MMNs elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group. With these stimulus conditions, all subjects were expected to have a MMN with normal latencies between 190 ms and 390 ms. No differences were expected in the MMNs of the Korean and American subjects because these people are structurally and physiologically the same. They should, therefore, process acoustic information similarly.

A one-way MANOVA was again used with these two taped conditions. For Tape Two, data were recorded (MMN present) from ten American-English Proficient subjects, five Proficient Korean subjects, and three Non-Proficient Korean subjects. For Tape Three, data were available (MMN present) from ten American-English Proficient subjects, nine Proficient Korean subjects, and six Non-Proficient Korean subjects. The means and standard deviations for the MMN latencies, amplitudes, and difference scores can be seen in Tables 3 and 4.

The Wilks' Lambda reported for the MANOVA obtained with Tape Two data indicated that there was not a significant difference among the three groups ($F(6,26) = .614$; $p = .717$). The Wilks' Lambda obtained with Tape Three data also indicated that there was not a significant difference between these three groups ($F(6,40) = .302$;

Table 3

Descriptive Statistics Table for the MMN Elicited by the La80/Ra20
Steady Interstimulus Interval Tape (Tape Two)

	Proficiency	Mean	sd	N
LATENCY	Prof. English	327.00	35.9	10
	Prof. Korean	312.00	22.8	5
	NonProf. Korean	330.00	10.0	3
INFREQUENT AMPLITUDE	Prof. English	1818.6	58.0	10
	Prof. Korean	1833.6	22.2	5
	NonProf. Korean	1829.6	42.1	3
NEGATIVITY	Prof. English	33.8	23.6	10
	Prof. Korean	42.2	21.8	5
	NonProf. Korean	17.0	15.4	3

Note. Means, standard deviations, and number of subjects from which the latencies, amplitudes of the infrequent waveform, and the negativity between the infrequent and frequent waveforms were recorded.

Table 4

Descriptive Statistics Table for the MMN Elicited by the La20/Ra80 Steady Interstimulus Interval Tape (Tape Three)

	Proficiency	Mean	sd	N
LATENCY	Prof. English	330.00	18.3	10
	Prof. Korean	338.89	16.9	9
	NonProf. Korean	328.33	25.6	6
INFREQUENT AMPLITUDE	Prof. English	1827.5	65.2	10
	Prof. Korean	1829.1	33.8	9
	NonProf. Korean	1818.5	48.2	6
NEGATIVITY	Prof. English	33.2	21.3	10
	Prof. Korean	31.3	18.2	9
	NonProf. Korean	30.7	13.0	6

Note. Means, standard deviations, and number of subjects from which the latencies, amplitudes of the infrequent waveform, and the negativity between the infrequent and frequent waveforms were recorded.

$p = .932$). Therefore, it was determined that there were no differences in the MMNs elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group. Because of this finding with these MANOVA, no further statistical analyses were necessary; however, two univariate ANOVA tables can be seen in Table 5 and 6 to demonstrate that the Bonferroni approach would not find significance either.

La20/Ra80 Variable Interstimulus Interval

Tape Four (La20/Ra80 Variable ISI) was used to determine if there were differences in the latencies and amplitudes of the P300s elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group. Tape Four was expected to elicit a P300 from all subjects; however, the latencies were expected to vary depending on the speaker's proficiency with /ra/ and /la/. That is, the presence or absence of the P300 was expected to be a function of the subject's language proficiency. The American-English listeners and the Proficient Korean listeners should have near-normal latencies (250 to 450 ms), while the Non-Proficient Korean listeners were expected to have delayed latencies (approx. 360 to 480 ms). The amplitudes of the P300 were also expected to be decreased in the Non-Proficient Korean group.

Table 5

Univariate ANOVA Tables for the MMN Elicited by Tape Two

Source	Type III SS	df	Mean Square	F Value	Pr > F (p)
GROUP LATENCY	910.000	2	455.000	.491	.621
ERROR	13890.00	15	926.000		
GROUP AMPLITUDE	842.011	2	421.006	.176	.840
ERROR	35848.27	15	2389.884		
GROUP AMP DIFF	1192.578	2	596.289	1.213	.325
ERROR	7373.200	15	491.547		

Note: These ANOVA tables support MANOVA results indicating that there were no differences in the latencies and amplitudes of the MMNs elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group.

Table 6

Univariate ANOVA Tables for the MMN Elicited by Tape Three

Source	Type III SS	df	Mean Square	F Value	Pr > F (p)
GROUP LATENCY	531.778	2	265.889	.682	.516
ERROR	8572.222	22	389.646		
GROUP AMPLITUDE	446.951	2	223.476	.083	.920
ERROR	59020.89	22	2682.768		
GROUP AMP DIFF	28.907	2	14.453	.042	.959
ERROR	7568.933	22	344.042		

Note: These ANOVA tables support MANOVA results indicating that there were no differences in the latencies and amplitudes of the MMNs elicited by /r/ and /l/ phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group.

A one-way MANOVA was used, and data were recorded (P300 present) from thirteen American-English Proficient subjects, eight Proficient Korean subjects, and five Non-Proficient Korean subjects. The means and standard deviations for the P300 latencies, amplitudes, and difference scores can be seen in Table 7.

The Wilks' Lambda reported for this MANOVA indicated that again there was not a significant difference among the three groups ($F(6,42) = 1.296$; $p = .280$). Therefore, it was determined that there were no differences in the latencies and amplitudes of the P300s elicited by /r/ and // phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group. Because of the findings with this MANOVA, no further statistical analyses were necessary; however, a univariate ANOVA table can be seen in Table 8 to demonstrate that the Bonferroni approach would find no significance.

Behavioral Scores Versus Electrophysiological Measures

All behavioral, latency, amplitude, and difference measures were examined for normality using normal Quantile-Quantile (Q-Q) plots (Appendix L). All measures, except for the AB measure, were found to be normally distributed. Therefore, both a Pearson Correlation matrix and a Spearman Correlation matrix were used with all measures to determine if there was a relationship between the behavioral test scores (AB and ABX) and the electrophysiological measures of these subjects. The behavioral results were similar for

Table 7

Descriptive Statistics Table for the P300 Elicited by the La20/Ra80
Variable Interstimulus Interval Tape (Tape Four)

	Proficiency	Mean	sd	N
LATENCY	Prof. English	400.77	35.5	13
	Prof. Korean	392.50	29.2	8
	NonProf. Korean	424.00	26.1	5
INFREQUENT AMPLITUDE	Prof. English	1931.1	58.0	13
	Prof. Korean	1912.5	63.1	8
	NonProf. Korean	1950.0	68.1	5
AMPLITUDE DIFFERENCE	Prof. English	57.4	40.8	13
	Prof. Korean	45.4	27.6	8
	NonProf. Korean	113.2	85.2	5

Note. Means, standard deviations, and number of subjects from which the latencies, amplitudes of the infrequent waveform, and the amplitude differences between the infrequent and frequent waveforms were recorded.

Table 8

Univariate ANOVA Tables for the P300 Elicited by Tape Four

Source	Type III SS	df	Mean Square	F Value	Pr > F (p)
GROUP LATENCY	3149.231	2	1574.615	1.524	.239
ERROR	23762.31	23	1033.144		
GROUP AMPLITUDE	4439.077	2	2219.538	.588	.564
ERROR	86842.92	23	3775.779		
GROUP AMP DIFF	15442.59	2	7721.297	3.270	.056
ERROR	54311.75	23	2361.381		

Note: These ANOVA tables support MANOVA results indicating that there were no differences in the latencies and amplitudes of the P300s elicited by /r/ and // phonemic stimuli among the Korean group proficient in English, the Korean group not proficient in English, and the American-English group.

the American-English group and the Proficient Korean group; therefore, it would be expected that the latencies, amplitudes, and difference scores would be similar. However, the Non-Proficient Koreans had significantly poorer behavioral test results, so the latencies, amplitudes, and difference scores would be expected to be less.

The correlation matrices indicated that a statistically significant relationship existed between the AB and ABX tasks (.557; $p = .001$) and between the amplitude difference of Tape Four (T4AMPDIF) and the ABX task (-.609, $p = .001$) (Table 9). However, when the data points were graphed onto a scatter plot, two out-lying points were noted to have caused the statistical program to determine significance, when in fact, no significance was present (see Appendix M). Therefore, it was determined that there was not a relationship between the behavioral test scores and the electrophysiological measures (amplitude, latency, and difference scores) for the American-English, Proficient Korean, or Non-Proficient Korean subjects. The Non-Proficient Koreans did not exhibit significantly delayed latencies or significantly lower amplitudes, even though they performed significantly poorer on the behavioral tasks.

Table 9

Pearson Correlation Matrix for Behavioral and Electrophysiological Measures

		AB	ABX	N
Pearson Correlation	AB	1.000	.557**	32
	ABX	.557**	1.000	32
	T1CZLAT	-.033	.097	23
	T1CZINFA	.020	.100	23
	T1AMPDIF	.229	.114	23
	T2FZLAT	-.022	-.350	18
	T2FZINFA	-.162	.161	18
	T2NEG	-.179	-.046	18
	T3FZLAT	-.162	-.018	25
	T3FZINFA	-.027	.156	25
	T3NEG	.079	.154	25
	T4CZLAT	-.162	-.329	26
	T4CZINFA	-.219	-.095	26
	T4AMPDIF	-.180	-.609**	26

Note. 'T1' refers to Tape One; 'T2' refers to Tape Two; 'T3' refers to Tape Three; 'T4' refers to Tape Four. 'FZ' and 'CZ' refer to the location of the electrode on the scalp from which the measurement was read. 'LAT' refers to the latency of the wave; 'INFA' refers to the infrequent waveform's amplitude; 'AMPDIF' refers to the difference between the infrequent and frequent waves of the P300; and 'NEG' refers to the negativity of the MMN. The two asterisks (**) mean that the correlation is significant at the .01 level.

Table 9 (cont.)

Pearson Correlation Matrix for Behavioral and Electrophysiological Measures

		AB	ABX	N
Significance (2-tailed)	AB	.	.001	32
	ABX	.001	.	32
	T1CZLAT	.881	.659	23
	T1CZINFA	.928	.649	23
	T1AMPDIF	.294	.604	23
	T2FZLAT	.931	.154	18
	T2FZINFA	.520	.524	18
	T2NEG	.477	.855	18
	T3FZLAT	.440	.932	25
	T3FZINFA	.899	.456	25
	T3NEG	.706	.463	25
	T4CZLAT	.429	.101	26
	T4CZINFA	.281	.643	26
	T4AMPDIF	.380	.001	26

Note. The matrix indicates that a significant relationship exists between the AB and ABX tasks and between the amplitude difference of Tape Four and the ABX task; however, the scatter plots (see Appendix L) revealed out-liers, which caused the statistical program to determine significance when no real significance was present.

CHAPTER V

DISCUSSION

Behavioral Tasks

AB and ABX discrimination tasks were used as the behavioral measures of perception, and the ABX task was used to label the Koreans as "Proficient" or "Non-Proficient." As seen in Figure 2 (page 54), the Korean subjects, both proficient and non-proficient, performed poorer (on average) than the American-English subjects. There was not a statistically significant difference between the American-English subjects and the Proficient Korean subjects; however, there was a statistically significant difference between the American-English subjects and the Non-Proficient Korean subjects and between the Proficient Korean subjects and the Non-Proficient Korean subjects ($F(2,29) = 33.3$; $p = .000$). These results support the findings of Mochizuki (1981), Henly and Sheldon (1986), and Flege (1988).

Proficiency Labeling

The three elicited speech samples obtained from the Korean subjects were to be used originally, in conjunction with the behavioral tasks, to categorize the Korean subjects into two different groups of proficiency. The AB and ABX tasks were intended to be used as a "screening device" to allow only those subjects who

scored 80% or above to be placed in the "Proficient" category, and those subjects who scored 60% or below to be placed in the "Non-Proficient" category. The subjects who scored in the 61% to 79% range were to be eliminated from the electrophysiological testing, as not representative of either "Proficient" or "Non-Proficient."

It became evident after testing only a few subjects that most Koreans did very well (85% or better) on the AB task and fairly well (70% or better) on the ABX task. There was no clear demarkation between proficient and non-proficient Koreans. Because a large majority of the AB and ABX scores fell between 61% to 79%, the investigator ran the risk of eliminating too many available Korean subjects, which would result in a non-representative sample. Therefore, the ABX discrimination task was used to separate the Korean subjects into groups of eleven Proficient Koreans and eight Non-Proficient Koreans. Subjects with ABX scores of 80% to 100% were termed "Proficient," and scores of 53% to 75% were termed "Non-Proficient."

Odd Tones Variable ISI Tape

The American-English subjects and the Korean subjects, regardless of proficiency, produced P300 responses between 250 ms and 450 ms post-stimulus onset with the Odd Tone Variable ISI tape (Tape One). There were no significant differences among these groups' latencies or amplitudes, which indicates that the task was equally difficult (or easy) for the three groups. This finding is

consistent with the hypothesis that the task of identifying infrequent low tones is not more difficult for one group than the other. This supports Miyawaki and colleagues (1975), who found that discrimination of non-speech stimuli was identical for Japanese and American subjects. It can be concluded that these three groups of subjects were not different neurologically or neurophysiologically.

La80/Ra20 and La20/Ra80 Steady ISI Tapes

The American-English subjects and the Korean subjects, regardless of proficiency, produced MMNs between 290 ms and 390 ms post-stimulus onset with the two steady ISI tapes (Tapes Two and Three). There were no significant differences among these groups' latencies or amplitudes for either tape. This indicates that the Koreans were capable of distinguishing a difference in these /ra/ and /la/ stimuli neurophysiologically, similar to the American-English subjects. Therefore, it can be concluded that this acoustic variation generated similar responses in all subjects, regardless of language skill. The purpose of doing both ra/la and la/ra contrasts was to insure that the MMN was a function of the intended acoustic mismatch (to odd-ball paradigm), and not a function of the acoustic parameters of either the /ra/ or /la/.

La20/Ra80 Variable ISI Tape

The American-English subjects and the Korean subjects, regardless of proficiency, produced P300 responses between 350 ms and 460 ms post-stimulus onset with the La20/Ra80 Variable ISI tape (Tape Four). There were no statistically significant differences among these groups' latencies or amplitudes. These findings were not anticipated because it had been hypothesized that the latency and amplitude responses would be a function of the subject's language proficiency. That is, the American-English listeners and the Proficient Korean listeners were expected to have near-normal P300 latencies, while the Non-Proficient Korean listeners were expected to have delayed latencies. The amplitudes of the P300s were also expected to be decreased in the Non-Proficient Korean group.

When the mean data were graphed for the three groups (Figure 9), the Non-Proficient Korean group *appeared* to have the longest P300 latencies. However, if the responses were to occur as hypothesized, the graph would have shown a progression in latency, with the Proficient Koreans having longer latencies than the English group, and the Non-Proficient Koreans having longer latencies than the Proficient Koreans. This progression did not occur. Therefore, there were no differences among these groups.

These findings may be the direct result of having a group of Korean subjects who were too homogeneous. Even with the AB and ABX behavioral tasks used as a screening procedure, and speech

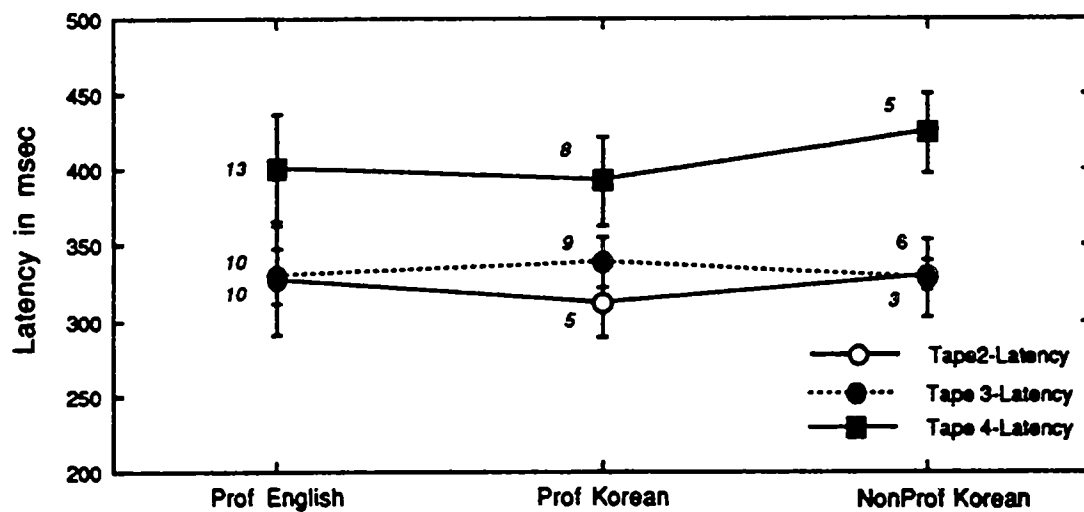


Figure 9. Graphed mean latency data for the MMNs and P300s elicited by the phonemic stimuli on Tapes Two through Four.

samples collected as a means of judging proficiency, the Korean subjects were not different enough in language skill. This is possibly due to the fact that the Korean nation has been exposed to English (in advertising, business, motion pictures, and music) since the early 1950s, following the Korean War. The Korean education system also formally teaches English starting in middle school. It is, in essence, impossible to find Koreans in the United States who have no experience with the English language. Therefore, it is difficult to find truly "non-proficient" Koreans.

In addition, it is possible that these subjects made their discriminations on an acoustic rather than linguistic basis. Because the stimuli used were phones of /ra/ and /la/, something in the characteristics of these specific productions may have allowed the subjects to discriminate between them easily.

A third possible reason why there were no significant differences found with this condition could be due to the large degree of variability found in the groups' mean latencies and amplitudes. The data in Table 7 (page 78) show that the standard deviations vary widely in the groups, both in latency and amplitude. This indicated that the American-English group, like the Korean group, was not as homogeneous as had been thought. This may be explained by the different incentives (internal and external) given to the American-English group. These subjects were given extra-credit in their classes, and they knew they would receive credit regardless of their performance during testing. Some subjects may have

desired to perform to the best of their abilities, while others may not have cared about their performance.

Behavioral Versus Electrophysiological Findings

Through the Pearson and Spearman correlation matrices, it was determined that there was not a relationship between the behavioral test scores and the electrophysiological measures (amplitude, latency, and difference scores) among the three groups of subjects. The Non-Proficient Koreans did not exhibit significantly delayed latencies or significantly lower amplitudes, even though they performed poorer on the behavioral tasks. With non-significant results in the Tape Four condition, this was not an unexpected finding. If there were no differences in the latencies and amplitudes among the groups, then a correlation would not be expected.

The apparent contradiction of a statistically significant difference in behavioral ABX scores for the non-proficient versus proficient subjects and the lack of significance in electrophysiological scores may be interpreted as a function of the relatively small number of subjects identified as "non-proficient," and/or the relative variability of the physiological measures.

Other Findings

Electrophysiological Measures. After the formatted data were averaged and automatic artifact rejection was performed on peak response amplitudes exceeding $\pm 45\mu\text{V}$, many Korean subjects were noted to have large artifact rejection values (over one-fourth of the total number of stimuli). These large values may have been due to the subjects' anxiety levels. Several subjects reported to the investigator that they were "nervous" during the testing. This anxiety may have been caused by the subjects' unfamiliarity with the English terms used in the experiment (although an interpreter was used for many of the non-proficient subjects). Only three of the thirteen (23%) English subjects had large artifact rejection values, whereas, nine out of nineteen (47%) Korean subjects had large rejection values. For example, K6 rejected 168 out of 200 stimuli for Tape One, 263 out of 400 stimuli for Tape Two, 313 out of 400 stimuli for Tape Three, and 146 out of 200 stimuli for Tape Four. This particular subject had no identifiable P300 for Tapes One and Four, and no identifiable MMN for Tape 2.

Other subjects (i.e., K1, K7, K15) revealed larger amplitudes for the frequent stimuli than for the infrequent stimuli in the P300 waveform of Tape Four. Although the subjects had been assigned the task of pushing a button on the infrequent // stimuli, these subjects appeared to have given more value to the frequent stimuli than to the infrequent stimuli. That is, they appeared to regard the

frequent /r/ stimuli as being more important, even though they were performing a task for the infrequent // stimuli.

The majority of ERP studies (for example, Aaltonen, Niemi, Nyrke and Tuhkanen, 1987; Pearce, Crowell, Tokioka, and Pacheco, 1989; Courchesne, 1978) used between 1200 and 2000 stimuli presentations to evoke a P300 and/or an MMN. Due to the limitations of the EPACS's software, only 400 stimuli could be presented for averaging. Some subjects may have exhibited a MMN or P300 with the presentation of more stimuli, especially considering the large amounts of artifact rejection. In an ERP, the potentials evoked by the stimuli are recorded on top to the existing background activity of the brain. The background activity, theoretically random, is expected to be reduced or eliminated by averaging the 400 individual formatted responses. It is not possible to meaningfully read a single formatted response to decide what is background activity and what has been evoked by the stimuli. Therefore, it is almost impossible to assign an interpretation to an averaged ERP when a large percentage of the individual trials have been rejected.

P300 Latencies. Although there was not a significant difference in the latencies and amplitudes of the P300 responses elicited by Tapes One or Four, it was noted that, upon visual inspection, there was a tendency for all subjects to have slightly delayed P300 responses with the /ra/ and /la/ stimuli when compared to the P300 responses obtained with the tonal stimuli.

For example, subject E2 had a P300 latency to tonal stimuli at 370 ms and a P300 latency to phonemic stimuli at 380 ms. Subject E3 had a P300 latency to tonal stimuli at 350 ms and a P300 latency to phonemic stimuli at 430 ms. The phenomenon was also present with the Korean subjects. Subject K3 had a P300 latency to tonal stimuli at 380 ms and a P300 latency to phonemic stimuli at 460 ms, and K5 had a P300 latency to tonal stimuli at 370 ms and a P300 latency to phonemic stimuli at 400 ms. On average, the P300 latency was 357.3 ms for the tones and 400.1 ms for the syllables with the English subjects. The P300 latencies were 364.2 ms for the tones and 412.3 ms for the syllables with the Korean subjects. This would indicate that the phonemic stimuli took longer to be processed than the tonal stimuli. Or in other words, the syllables are more difficult stimuli, and therefore, take longer to process than the easier tonal stimuli.

Implications for Future Research

It appears that prior linguistic knowledge of a second language is important to perception and production (Flege, 1988). Mochizuki (1981) showed that Japanese learners with greater English L2 experience succeed better in perceiving the English /r/ and /l/ phonemes. Further research with English L2 experience is needed in order to categorize listeners into "proficient" and "non-proficient" classifications.

In the present study, the subjects apparently made what was intended as a linguistic judgment on acoustic grounds. One possible way to insure that a linguistic judgment was required from subjects would be to embed the /r/ and // phonemes into words which would be expected or not expected in context. For example, both /r/ and // would be logical in phrases such as, "Turn to the light" versus "Turn to the right." They would be less logical in phrases such as, "Turn out the light" versus "Turn out the right."

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APPENDICES

APPENDIX A

Subject Information

SUBJECT INFORMATION

NAME: _____

ADDRESS: _____

PHONE NUMBER: _____

AGE: _____ NATIVE LANGUAGE: _____

ANY KNOWN NEUROPATHOLOGIES? yes no

IF JAPANESE OR KOREAN, NUMBER OF YEARS OF ENGLISH
STUDY: _____ yrs

ENGLISH TAUGHT BY: NATIVE ENGLISH INSTRUCTOR _____ yrs

 NATIVE JAP/KOR INSTRUCTOR _____ yrs

RANK YOUR PROFICIENCY WITH THE ENGLISH LANGUAGE ON A
SCALE FROM 1 (POOR) TO 10 (EXCELLENT) _____

In U.S.? _____ mos

HEARING SCREENING:

	RIGHT	LEFT
500 HZ	-----	-----
1000 HZ	-----	-----
2000 HZ	-----	-----
4000 HZ	-----	-----

APPENDIX B

Recruiting Notice

NEEDED

Native-Japanese and native-Korean speakers willing to participate in a study conducted in the UT Hearing and Speech Center (Yale Ave.). This study will use electrophysiological means for collecting information concerning the brain's ability to discriminate "R" and "L" sounds. Volunteers will be fully informed of all testing procedures prior to participation. Only 2 to 2 1/2 hours of your time is needed. You will be paid \$10.00 for your participation. If interested, please call Cindy at 974-1810. Leave a message if no answer.

APPENDIX C

AB Discrimination Task

Behavioral Testing

You will hear a tape recording of several presentations of the sounds "la" and "ra." In the spaces provided, CIRCLE the sound you hear after each presentation. If you have any questions, please ask the investigator before you begin this task.

RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA

RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA
RA	LA

APPENDIX D

ABX Discrimination Task

ABX Behavioral Testing

You will hear a tape recording with several presentations of the sounds "la" and "ra." You will hear series of three sounds in a row. Please listen to the first two sounds, and then decide if the third sound is more like the first sound or if it is more like the second sound. If the third sound is more like the first one, CIRCLE a "1" in the provided space. If the third sound is more like the second one, CIRCLE a "2" in the provided space. For example, you may hear "la - ra -la." You will then circle a "1" on your score sheet because the third sound was more like the first sound. If you have any questions, please ask the investigator before you begin this task.

1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2

1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2
1	2

APPENDIX E

The "My Grandfather" Passage



MY GRANDFATHER

You wished to know all about my grandfather. Well, he is nearly ninety-three years old, he dresses himself in an ancient black frockcoat, usually minus several buttons; yet he still thinks as swiftly as ever. A long, flowing beard clings to his chin, giving those who observe him a pronounced feeling of the utmost respect. When he speaks, his voice is just a bit cracked and quivers a trifle. Twice each day he plays skillfully and with zest upon our small organ. Except in the winter when the ooze of snow and ice prevents, he slowly takes a short walk in the open air each day. We have often urged him to walk more and smoke less, but he always answers, "Banana oil!" Grandfather likes to be modern in his language.

APPENDIX F
Pronunciation Test

Pronunciation Test

Initial Position

/r/	/l/
1. rain	lane
2. rag	lag
3. row	low
4. rip	lip
5. rake	lake
6. rye	lie
7. write	light
8. rhyme	lime
9. rid	lid
10. rope	lope

Medial Position

1. Harry	Haley
2. sorrow	hollow
3. worry	early
4. boring	bowling
5. daring	calling
6. Darren	Helen
7. Thursday	hallway
8. harvest	melted
9. jury	palm
10. orange	old

Final Position

1. care	kale
2. car	call
3. bar	ball
4. bear	bell
5. steer	steal
6. mare	male
7. dare	doll
8. oar	owl
9. more	mole
10. tear	tail

Blends

1. crew
2. trash
3. crash
4. brush
5. grip
6. gram
7. grope
8. tree
9. cream
10. preen

flew
flash
clash
blush
slip
slam
slope
flee
clean
please

Both phonemes present

1. carpool
2. lorry
3. coral
4. rule
5. lure
6. labor
7. cartwheel
8. solar
9. doornail
10. cooler

APPENDIX G
Judging Form

Judgment of Asian Subject Language Proficiency

Judge Number _____

Date _____

Subject's Number _____

GRANDFATHER PASSAGE:

How well does this subject read this passage?

Does he/she sound like a native English speaker?

Does his/her inflection sound natural to you?

Does he/she make any mistakes in pronunciation?

RATING SCALE of PROFICIENCY:

1 (poor) to 10 (excellent)

SCORE: _____ (use whole number)

CONVERSATIONAL SPEECH:

How easily does this subject answer the questions?

Does he/she sound like a native English speaker?

Does his/her inflection sound natural to you?

Does he/she make any mistakes in pronunciation?

RATING SCALE of PROFICIENCY:

1 (poor) to 10 (excellent)

SCORE: _____ (use whole number)

PRONUNCIATION TEST

Initial Position

/ r /

____/10 correct

/ l /

____/10 correct

Medial Position

/ r /

____/10 correct

/ l /

____/10 correct

Final Position

/ r /

____/10 correct

/ l /

____/10 correct

Blends

/ r /

____/10 correct

/ l /

____/10 correct

Both phonemes present

/ r /

____/10 correct

/ l /

____/10 correct

APPENDIX H

American-English Informed Consent Form

Consent Form

Mismatch Negativity and P300 Evoked Response Potentials: Perception and Discrimination of /r/ and /l/ in Asian and English Listeners

Project Objectives

The objective of this project is to determine if native Asian speakers perceive and discriminate English /ra/ and /la/ syllables, as determined with Mismatch Negativity (MMN) and P300 evoked response potentials. The data will be collected using the equipment of the Neurolinguistics Laboratory in room 21 of the Hearing and Speech Center.

Qualifying Criteria to Participate

You will have to meet the following criteria as determined by the principal investigator to participate in this study:

1. Normal pure tone hearing thresholds in at least one ear, as determined with screening procedure.
2. Primary (native) language is Korean, Japanese or English.
3. No known neurological disorders.

MMN and P300 Evoked Response Potential Measurement

1. You will listen to two tapes of /ra/ and /la/ syllables. In the first tape, you will write the syllable you hear on the form in front of you. In the second tape, you will hear a series of three syllables. Write a '1' if the third syllable you hear sounds more like the first one, and write a '2' if the third syllable you hear sounds more like the second one. A full set of directions will be given before each test. If you are a native-Japanese or native-Korean listener, you will be asked to read a short paragraph, read some words, and answer 3-4 general information questions while being tape recorded. These speech samples will be judged by a panel of 5 listeners to determine into which category of proficiency you fall.
2. You will have 6 electrodes placed on your scalp (F3, F4, P3, P4, Cz, and Fz), one on each ear as references, and one on the forehead as the ground (according to the 10-20 system). You will have the skin at each of these electrode sites scrubbed lightly in order to obtain the close contact (impedence) that is necessary for electrophysiological testing. Some people may have a red mark (abrasion) on the skin under the electrodes, but this will clear up shortly. No permanent damage will occur.
3. You will be seated in a comfortable chair inside a sound treated room in the Neurolinguistics Laboratory.
4. Taped recordings of an English speaker's syllables will be played through an overhead speaker at a comfortable listening level. You will listen to 4 cassette tapes, each approximately 10-12 minutes in length.
5. You will not be asked to attend to some tapes, and not attend to other tapes. You will watch a slide show and video during two of the tapes.
6. Testing will be completed in one session, and will take approximately 2 to 2 1/2 hours, including preparation and cleaning the electrode paste out of your hair when we finish.

Risk and Benefits

There are no significant risks associated with this project. The benefit of the project is that you will be contributing to the knowledge base of MMNs and P300s, which has great promise as a clinical measure. The results of the research may be presented at scientific meetings and/or published in scientific journals. Your research data will be strictly confidential and identified by number only. No identification of you will be given other than as a native Korean, native Japanese, or native American English speaker.

Privacy of Records

Your research data record will be identified by an assigned research number. Your name and research number will be kept confidential in a locked file. The research data record will include:

1. Your age, gender, and address
2. Results of the qualifying tests:
 - a. Pure tone thresholds
 - b. Native language - Korean, Japanese, or English
 - c. No neuropathology
3. Results of the behavioral tests (and proficiency rating, if Asian)
4. Results of the experimental MMN and P300 tests

YOUR PARTICIPATION IS COMPLETELY VOLUNTARY.

YOU MAY TERMINATE YOUR PARTICIPATION AT ANY TIME WITHOUT PREJUDICE TO ANY FUTURE CONTACT YOU MAY HAVE WITH THE HEARING AND SPEECH CENTER OR WITH THE UNIVERSITY OF TENNESSEE.

WHO TO CONTACT IF YOU HAVE CONCERNS:

If you have any concerns, please contact either of the principal investigators; Cynthia A. McCormick, M.A., 423/974-1810 or Harold A. Peterson, Ph.D., 423/974-4652.

PERMISSION TO PARTICIPATE

I agree to participate in this study.

Signature of Participant

Signature of Witness

Date

APPENDIX I

Asian Informed Consent Form

Consent Form

Mismatch Negativity and P300 Evoked Response Potentials: Perception and Discrimination of /r/ and /l/ in Asian and English Listeners

Project Objectives

The objective of this project is to determine if native Asian speakers perceive and discriminate English /ra/ and /la/ syllables, as determined with Mismatch Negativity (MMN) and P300 evoked response potentials. The data will be collected using the equipment of the Neurolinguistics Laboratory in room 21 of the Hearing and Speech Center. Asian speakers will be paid \$10.00 to participate, upon completion of data collection. A check from the department will be mailed to the participant's home address.

Qualifying Criteria to Participate

You will have to meet the following criteria as determined by the principal investigator to participate in this study:

1. Normal pure tone hearing thresholds in at least one ear, as determined with screening procedure.
2. Primary (native) language is Korean, Japanese or English.
3. No known neurological disorders.

MMN and P300 Evoked Response Potential Measurement

1. You will listen to two tapes of /ra/ and /la/ syllables. In the first tape, you will write the syllable you hear on the form in front of you. In the second tape, you will hear a series of three syllables. Write a '1' if the third syllable you hear sounds more like the first one, and write a '2' if the third syllable you hear sounds more like the second one. A full set of directions will be given before each test. If you are a native-Japanese or native-Korean listener, you will be asked to read a short paragraph, read some words, and answer 3-4 general information questions while being tape recorded. These speech samples will be judged by a panel of 5 listeners to determine into which category of proficiency you fall.
2. You will have 6 electrodes placed on your scalp (F3, F4, P3, P4, Cz, and Fz), one on each ear as references, and one on the forehead as the ground (according to the 10-20 system). You will have the skin at each of these electrode sites scrubbed lightly in order to obtain the close contact (impedance) that is necessary for electrophysiological testing. Some people may have a red mark (abrasion) on the skin under the electrodes, but this will clear up shortly. No permanent damage will occur.
3. You will be seated in a comfortable chair inside a sound treated room in the Neurolinguistics Laboratory.
4. Taped recordings of an English speaker's syllables will be played through an overhead speaker at a comfortable listening level. You will listen to 4 cassette tapes, each approximately 10-12 minutes in length.
5. You will not be asked to attend to some tapes, and not attend to other tapes. You will watch a slide show and video during two of the tapes.

6. Testing will be completed in one session, and will take approximately 2 to 2 -1/2 hours, including preparation and cleaning the electrode paste out of your hair when we finish.

Risk and Benefits

There are no significant risks associated with this project. The benefit of the project is that you will be contributing to the knowledge base of MMNs and P300s, which has great promise as a clinical measure. The results of the research may be presented at scientific meetings and/or published in scientific journals. Your research data will be strictly confidential and identified by number only. No identification of you will be given other than as a native Korean, native Japanese, or native American English speaker.

Privacy of Records

Your research data record will be identified by an assigned research number. Your name and research number will be kept confidential in a locked file. The research data record will include:

1. Your age, gender, and address
2. Results of the qualifying tests:
 - a. Pure tone thresholds
 - b. Native language - Korean, Japanese, or English
 - c. No neuropathology
3. Results of the behavioral tests (and proficiency rating, if Asian)
4. Results of the experimental MMN and P300 tests

YOUR PARTICIPATION IS COMPLETELY VOLUNTARY.
YOU MAY TERMINATE YOUR PARTICIPATION AT ANY TIME WITHOUT
PREJUDICE TO ANY FUTURE CONTACT YOU MAY HAVE WITH THE HEARING
AND SPEECH CENTER OR WITH THE UNIVERSITY OF TENNESSEE; HOWEVER,
YOU WILL NOT RECEIVE PAYMENT UNLESS FULL DATA IS COLLECTED.

WHO TO CONTACT IF YOU HAVE CONCERNS:

If you have any concerns, please contact either of the principal investigators; Cynthia A. McCormick, M.A., 423/974-1810 or Harold A. Peterson, Ph.D., 423/974-4652.

PERMISSION TO PARTICIPATE

I agree to participate in this study.

Signature of Participant

Signature of Witness

Date

APPENDIX J

American-English Subjects' Raw Data

KEY

- 'subject' - "E" refers to English subjects, "K" refers to Korean subjects.
- 'gender' - Categorizes "males" and "females."
- 'language' - Categorizes "English" and "Korean."
- 'proficny' - Categorizes the "Proficient" and "Non-Proficient" subjects.
- 'threepro' - Differentiates the groups into Proficient English (proeng), Proficient Korean (prokor), and Non-Proficient Korean (nonprokor).
- 'age' - Age of subjects, in years.
- 'hand'* - Handedness of subjects, as determined with the Edinburgh Handedness Inventory (Oldfield, 1971)
- 'selfrate'* - The Korean subjects' self rating of their proficiency with English.
- 'ab' - The scores obtained on the AB behavioral task.
- 'abx' - The scores obtained on the ABX behavioral task.
- 'engstdyr'* - The number of years the subjects have studied English.
- 't1czlat' - The latency response obtained with Tape One, at the CZ location.
- 't1czinfa' - The amplitude response of the infrequent wave obtained with Tape One, at the CZ location.
- 't1czfrqa' - The amplitude response of the frequent wave obtained with Tape One, at the CZ location.
- 't1ampdif' - The difference between the amplitudes of the infrequent and frequent waves obtained with Tape One.
- 't2fzlat' - The latency response obtained with Tape Two, at the FZ location.
- 't2fzinfa' - The amplitude response of the infrequent wave obtained with Tape Two, at the FZ location.
- 't2fzfrqa' - The amplitude response of the frequent wave obtained with Tape Two, at the FZ location.
- 't2neg' - The negativity between the amplitudes of the infrequent and frequent waves obtained with Tape Two.
- 't3fzlat' - The latency response obtained with Tape Three, at the FZ location.
- 't3fzinfa' - The amplitude response of the infrequent wave obtained with Tape Three, at the FZ location.
- 't3fzfrqa' - The amplitude response of the frequent wave obtained with Tape Three, at the FZ location.
- 't3neg' - The negativity between the amplitudes of the infrequent and frequent waves obtained with Tape Three.
- 't4czlat' - The latency response obtained with Tape Four, at the CZ location.
- 't4czinfa' - The amplitude response of the infrequent wave obtained with Tape Four, at the CZ location.
- 't4czfrqa' - The amplitude response of the frequent wave obtained with Tape Four, at the CZ location.
- 't4ampdif' - The difference between the amplitudes of the infrequent and frequent waves obtained with Tape Four.
- 'months'* - Number of months the subjects have lived in the United States.

(* refers to data not used in this study/ not used with this group)

subject	gender	language	proficny	threepro	age	hand
1 E1	Female	English	Proficient	proeng	23.00	right
2 E2	Male	English	Proficient	proeng	22.00	right
3 E3	Female	English	Proficient	proeng	21.00	right
4 E5	Male	English	Proficient	proeng	39.00	right
5 E6	Female	English	Proficient	proeng	21.00	right
6 E7	Female	English	Proficient	proeng	21.00	right
7 E8	Female	English	Proficient	proeng	33.00	right
8 E9	Female	English	Proficient	proeng	25.00	right
9 E10	Male	English	Proficient	proeng	21.00	right
10 E11	Female	English	Proficient	proeng	21.00	right
11 E12	Male	English	Proficient	proeng	20.00	right
12 E13	Female	English	Proficient	proeng	24.00	right
13 E14	Female	English	Proficient	proeng	21.00	right

	selfrate	ab	abx	engstdyr	t1czlat	t1czinfa	t1czfrqa
1	10.00	100.00	98.00	23.00	360.00	2013.00	1856.00
2	10.00	100.00	98.00	22.00	370.00	1836.00	1822.00
3	10.00	100.00	70.00	21.00	350.00	1913.00	1748.00
4	10.00	100.00	93.00	39.00	370.00	1933.00	1767.00
5	10.00	100.00	85.00	21.00			
6	10.00	100.00	95.00	21.00	310.00	1848.00	1710.00
7	10.00	100.00	100.00	33.00	380.00	1918.00	1797.00
8	10.00	100.00	98.00	25.00	330.00	1981.00	1764.00
9	10.00	100.00	100.00	21.00	380.00	1886.00	1819.00
10	10.00	100.00	100.00	21.00	370.00	2055.00	1964.00
11	10.00	100.00	100.00	20.00			
12	10.00	100.00	100.00	24.00	360.00	1998.00	1796.00
13	10.00	100.00	100.00	21.00	350.00	1997.00	1847.00

	t1ampdif	t2fzlat	t2fzinf	t2fzfrqa	t2neg	t3fzlat	t3fzinf
1	157.00	290.00	1770.00	1829.00	59.00	300.00	1827.00
2	14.00	310.00	1778.00	1836.00	58.00	310.00	1826.00
3	165.00	390.00	1792.00	1859.00	67.00		
4	166.00					340.00	1719.00
5		320.00	1775.00	1809.00	34.00		
6	138.00	310.00	1853.00	1879.00	26.00		
7	121.00	390.00	1849.00	1862.00	13.00	340.00	1861.00
8	217.00	320.00	1820.00	1825.00	5.00	340.00	1819.00
9	67.00					340.00	1761.00
10	91.00					360.00	1836.00
11		300.00	1956.00	1962.00	6.00	310.00	1924.00
12	202.00	340.00	1767.00	1783.00	16.00	330.00	1923.00
13	150.00	300.00	1826.00	1876.00	50.00	330.00	1779.00

	t3fzfrqa	t3neg	t4czlat	t4czinfa	t4czfrqa	t4ampdif	months
1	1835.00	8.00	350.00	1883.00	1826.00	57.00	276.00
2	1850.00	24.00	380.00	1895.00	1865.00	30.00	264.00
3	.	.	430.00	1973.00	1825.00	148.00	252.00
4	1779.00	60.00	450.00	1950.00	1837.00	113.00	468.00
5	.	.	360.00	1921.00	1839.00	82.00	252.00
6	.	.	430.00	1874.00	1832.00	42.00	252.00
7	1870.00	9.00	460.00	1907.00	1815.00	92.00	396.00
8	1875.00	56.00	390.00	1924.00	1870.00	54.00	300.00
9	1813.00	52.00	390.00	1884.00	1852.00	32.00	252.00
10	1886.00	50.00	410.00	2099.00	2095.00	4.00	252.00
11	1968.00	44.00	420.00	1945.00	1903.00	42.00	240.00
12	1931.00	8.00	380.00	1923.00	1893.00	30.00	288.00
13	1800.00	21.00	360.00	1926.00	1906.00	20.00	252.00

APPENDIX K

Korean Subjects' Raw Data

KEY

- 'subject' - "E" refers to English subjects, "K" refers to Korean subjects.
- 'gender' - Categorizes "males" and "females."
- 'language' - Categorizes "English" and "Korean."
- 'proficny' - Categorizes the "Proficient" and "Non-Proficient" subjects.
- 'threepro' - Differentiates the groups into Proficient English (proeng), Proficient Korean (prokor), and Non-Proficient Korean (nonprokor).
- 'age' - Age of subjects, in years.
- 'hand'* - Handedness of subjects, as determined with the Edinburgh Handedness Inventory (Oldfield, 1971)
- 'selfrate' - The Korean subjects' self rating of their proficiency with English.
- 'ab' - The scores obtained on the AB behavioral task.
- 'abx' - The scores obtained on the ABX behavioral task.
- 'engstdyr' - The number of years the subjects have studied English.
- 't1czlat' - The latency response obtained with Tape One, at the CZ location.
- 't1czinfa' - The amplitude response of the infrequent wave obtained with Tape One, at the CZ location.
- 't1czfrqa' - The amplitude response of the frequent wave obtained with Tape One, at the CZ location.
- 't1ampdif' - The difference between the amplitudes of the infrequent and frequent waves obtained with Tape One.
- 't2fzlat' - The latency response obtained with Tape Two, at the FZ location.
- 't2fzinfa' - The amplitude response of the infrequent wave obtained with Tape Two, at the FZ location.
- 't2fzfrqa' - The amplitude response of the frequent wave obtained with Tape Two, at the FZ location.
- 't2neg' - The negativity between the amplitudes of the infrequent and frequent waves obtained with Tape Two.
- 't3fzlat' - The latency response obtained with Tape Three, at the FZ location.
- 't3fzinfa' - The amplitude response of the infrequent wave obtained with Tape Three, at the FZ location.
- 't3fzfrqa' - The amplitude response of the frequent wave obtained with Tape Three, at the FZ location.
- 't3neg' - The negativity between the amplitudes of the infrequent and frequent waves obtained with Tape Three.
- 't4czlat' - The latency response obtained with Tape Four, at the CZ location.
- 't4czinfa' - The amplitude response of the infrequent wave obtained with Tape Four, at the CZ location.
- 't4czfrqa' - The amplitude response of the frequent wave obtained with Tape Four, at the CZ location.
- 't4ampdif' - The difference between the amplitudes of the infrequent and frequent waves obtained with Tape Four.
- 'months' - Number of months the subjects have lived in the United States.
- 'judge1gf' - First judge's score for the Grandfather passage.
- 'judge1qn' - First judge's score for the Interview Questions.
- 'judge1wd' - First judge's score for the Pronunciation Test words.

'judge2gf' - Second judge's score for the Grandfather passage.
'judge2qn' - Second judge's score for the Interview Questions.
'judge2wd' - Second judge's score for the Pronunciation Test words.
'judge3gf' - Third judge's score for the Grandfather passage.
'judge3qn' - Third judge's score for the Interview Questions.
'judge3wd' - Third judge's score for the Pronunciation Test words.
'judge4gf' - Fourth judge's score for the Grandfather passage.
'judge4qn' - Fourth judge's score for the Interview Questions.
'judge4wd' - Fourth judge's score for the Pronunciation Test words.
'judge5gf' - Fifth judge's score for the Grandfather passage.
'judge5qn' - Fifth judge's score for the Interview Questions.
'judge5wd' - Fifth judge's score for the Pronunciation Test words.
'judge6gf' - Sixth judge's score for the Grandfather passage.
'judge6qn' - Sixth judge's score for the Interview Questions.
'judge6wd' - Sixth judge's score for the Pronunciation Test words.

(* refers to data not used in this study/ not used with this group)

subject	gender	language	proficny	threepro	age	hand
14 K1	Female	Korean	Proficient	prokor	29.00	right
15 K2	Female	Korean	Proficient	prokor	33.00	right
16 K3	Male	Korean	Nonprofcnt	nonprokor	27.00	left
17 K4	Female	Korean	Proficient	prokor	26.00	right
18 K5	Female	Korean	Proficient	prokor	30.00	right
19 K6	Female	Korean	Nonprofcnt	nonprokor	21.00	right
20 K7	Male	Korean	Proficient	prokor	24.00	right
21 K8	Male	Korean	Proficient	prokor	20.00	right
22 K9	Male	Korean	Nonprofcnt	nonprokor	26.00	right
23 K10	Male	Korean	Nonprofcnt	nonprokor	23.00	left
24 K11	Male	Korean	Nonprofcnt	nonprokor	25.00	right
25 K12	Male	Korean	Proficient	prokor	26.00	right
26 K13	Female	Korean	Nonprofcnt	nonprokor	31.00	right
27 K14	Female	Korean	Nonprofcnt	nonprokor	29.00	right
28 K15	Female	Korean	Nonprofcnt	nonprokor	21.00	right
29 K16	Male	Korean	Proficient	prokor	24.00	right
30 K17	Male	Korean	Proficient	prokor	31.00	right
31 K18	Female	Korean	Proficient	prokor	30.00	right
32 K19	Female	Korean	Proficient	prokor	20.00	right
33						

	selfrate	ab	abx	engstdyr	t1czlat	t1czinfa	t1czfrqa
14	5.00	100.00	85.00	7.50	380.00	1883.00	1852.00
15	5.00	98.00	95.00	6.00	350.00	1991.00	1846.00
16	7.00	98.00	70.00	8.00	380.00	1905.00	1810.00
17	3.00	98.00	85.00	8.00	.	.	.
18	7.00	100.00	93.00	8.00	370.00	1881.00	1826.00
19	3.00	78.00	53.00	9.00	.	.	.
20	3.00	98.00	88.00	8.00	.	.	.
21	9.00	100.00	85.00	5.00	.	.	.
22	5.00	95.00	70.00	7.00	350.00	1879.00	1861.00
23	6.00	70.00	75.00	7.00	390.00	1909.00	1857.00
24	6.00	93.00	68.00	8.00	370.00	1879.00	1815.00
25	7.00	100.00	93.00	10.00	370.00	1896.00	1750.00
26	3.00	73.00	65.00	8.00	340.00	1939.00	1876.00
27	2.00	85.00	73.00	7.00	340.00	2010.00	1793.00
28	5.00	100.00	70.00	10.00	350.00	2025.00	1839.00
29	2.00	93.00	80.00	6.00	.	.	.
30	7.00	95.00	100.00	10.00	380.00	1888.00	1859.00
31	3.00	70.00	85.00	10.00	.	.	.
32	5.00	100.00	100.00	8.00	.	.	.
33	.	.	.	.	.	.	.

	t1ampdif	t2fzlat	t2fzinf	t2fzfrqa	t2neg	t3fzlat	t3fzinf
14	31.00	340.00	1819.00	1848.00	29.00	330.00	1839.00
15	145.00	.	.	.	.	340.00	1892.00
16	95.00	320.00	1801.00	1805.00	4.00	310.00	1823.00
17	.	.	.	.	.	340.00	1800.00
18	55.00	290.00	1869.00	1880.00	11.00	.	.
19	.	.	.	.	.	320.00	1847.00
20	.	330.00	1825.00	1890.00	65.00	350.00	1770.00
21	.	.	.	.	.	340.00	1840.00
22	18.00	.	.	.	.	.	.
23	52.00	340.00	1878.00	1912.00	34.00	320.00	1895.00
24	64.00	.	.	.	.	320.00	1797.00
25	146.00	290.00	1841.00	1893.00	52.00	320.00	1847.00
26	63.00	.	.	.	.	380.00	1792.00
27	217.00	.	.	.	.	320.00	1757.00
28	186.00	330.00	1810.00	1823.00	13.00	.	.
29	.	.	.	.	.	360.00	1812.00
30	29.00	.	.	.	.	360.00	1833.00
31	.	310.00	1814.00	1868.00	54.00	.	.
32	.	.	.	.	.	310.00	1829.00
33	.	.	.	.	.	.	.

	t3fzfrqa	t3neg	t4czlat	t4czinfa	t4czfrqa	t4ampdif	months
14	1859.00	20.00	.	.	.	.	36.00
15	1908.00	16.00	350.00	2010.00	1985.00	25.00	84.00
16	1863.00	40.00	460.00	1895.00	1853.00	42.00	6.00
17	1808.00	8.00	350.00	1819.00	1796.00	23.00	2.50
18	.	.	400.00	1933.00	1852.00	81.00	24.00
19	1874.00	27.00	.	.	.	.	3.00
20	1800.00	30.00	.	.	.	.	3.00
21	1881.00	41.00	410.00	1846.00	1819.00	27.00	60.00
22	.	.	.	.	.	.	6.00
23	1913.00	18.00	410.00	1989.00	1890.00	99.00	3.00
24	1811.00	14.00	390.00	2047.00	1793.00	254.00	10.00
25	1888.00	41.00	.	.	.	.	8.50
26	1831.00	39.00	.	.	.	.	48.00
27	1803.00	46.00	430.00	1884.00	1833.00	51.00	3.00
28	.	.	430.00	1935.00	1815.00	120.00	6.00
29	1826.00	14.00	420.00	1896.00	1827.00	69.00	3.00
30	1993.00	60.00	410.00	1893.00	1884.00	9.00	4.00
31	.	.	420.00	1975.00	1901.00	74.00	36.00
32	1881.00	52.00	380.00	1928.00	1873.00	55.00	60.00
33	.	.	.	.	.	.	.

	judge1gf	judge1qn	judge1wd	judge2gf	judge2qn	judge2wd	judge3gf
14	10.00	10.00	92.00	7.00	8.00	92.00	9.00
15	7.00	8.00	86.00	6.00	6.00	82.00	6.00
16	5.00	4.00	66.00	4.00	4.00	80.00	4.00
17	3.00	2.00	70.00	4.00	5.00	84.00	3.00
18	4.00	6.00	82.00	7.00	8.00	96.00	6.00
19	2.00	2.00	66.00	4.00	5.00	58.00	3.00
20	3.00	4.00	84.00	8.00	8.00	74.00	5.00
21	8.00	9.00	90.00	8.00	10.00	98.00	9.00
22	3.00	1.00	54.00	2.00	2.00	68.00	2.00
23	3.00	3.00	68.00	4.00	6.00	76.00	5.00
24	5.00	4.00	62.00	4.00	5.00	78.00	5.00
25	7.00	7.00	96.00	7.00	7.00	82.00	7.00
26	4.00	5.00	72.00	5.00	6.00	74.00	6.00
27	3.00	3.00	80.00	4.00	3.00	66.00	4.00
28	2.00	4.00	78.00	7.00	9.00	88.00	5.00
29	3.00	3.00	56.00	5.00	3.00	60.00	4.00
30	7.00	8.00	84.00	7.00	6.00	80.00	7.00
31	3.00	5.00	84.00	8.00	8.00	58.00	5.00
32	6.00	8.00	90.00	8.00	10.00	94.00	6.00
33	.	.	.	.	.	.	.

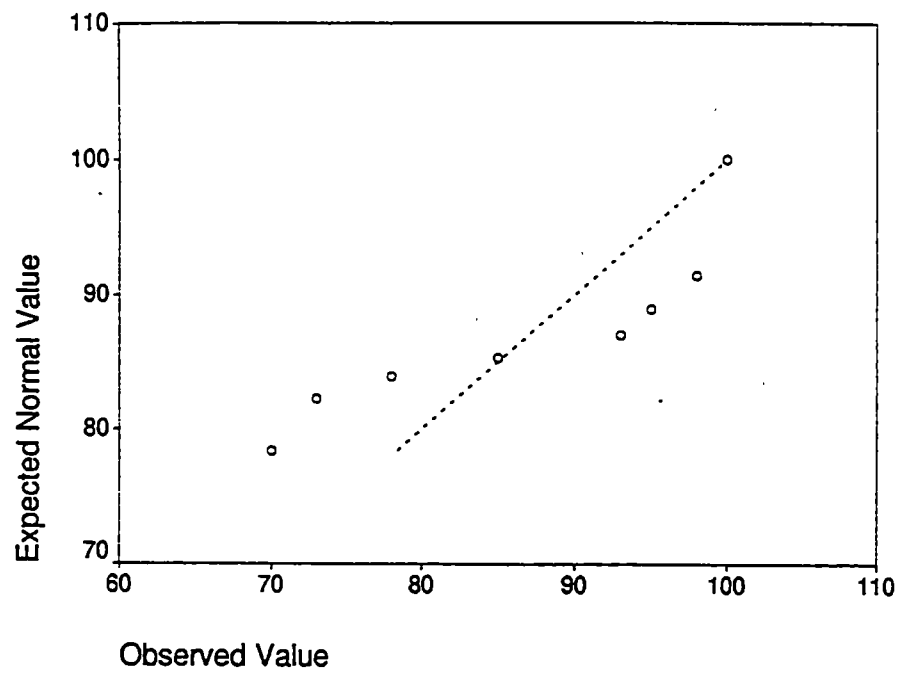
	judge3qn	judge3wd	judge4gf	judge4qn	judge4wd	judge5gf	judge5qn
14	9.00	100.00	9.00	9.00	98.00	9.00	9.00
15	7.00	98.00	6.00	6.00	94.00	6.00	5.00
16	5.00	90.00	5.00	4.00	90.00	5.00	4.00
17	3.00	96.00	6.00	7.00	88.00	5.00	5.00
18	7.00	100.00	7.00	9.00	96.00	7.00	7.00
19	3.00	88.00	6.00	5.00	84.00	5.00	4.00
20	4.00	92.00	6.00	7.00	88.00	6.00	6.00
21	10.00	98.00	8.00	8.00	94.00	9.00	10.00
22	2.00	84.00	5.00	3.00	82.00	4.00	2.00
23	5.00	82.00	7.00	6.00	86.00	6.00	4.00
24	5.00	96.00	6.00	6.00	82.00	6.00	5.00
25	8.00	100.00	8.00	8.00	94.00	8.00	7.00
26	6.00	92.00	7.00	8.00	86.00	6.00	7.00
27	4.00	96.00	5.00	4.00	92.00	4.00	1.00
28	4.00	94.00	7.00	7.00	94.00	5.00	5.00
29	3.00	86.00	6.00	5.00	82.00	6.00	4.00
30	6.00	100.00	8.00	7.00	90.00	7.00	7.00
31	5.00	96.00	7.00	6.00	76.00	7.00	5.00
32	7.00	100.00	7.00	7.00	94.00	7.00	8.00
33	.	.	.	.	.	.	.

	judge5wd	judge6gf	judge6qn	judge6wd
14	92.00	9.00	9.00	98.00
15	68.00	5.00	8.00	88.00
16	38.00	3.00	3.00	88.00
17	68.00	2.00	3.00	78.00
18	94.00	3.00	5.00	96.00
19	58.00	2.00	2.00	80.00
20	66.00	2.00	4.00	82.00
21	96.00	4.00	9.00	96.00
22	58.00	2.00	2.00	74.00
23	78.00	3.00	3.00	70.00
24	74.00	2.00	4.00	74.00
25	76.00	5.00	6.00	100.00
26	72.00	4.00	5.00	84.00
27	68.00	4.00	2.00	78.00
28	88.00	3.00	4.00	92.00
29	74.00	3.00	2.00	74.00
30	84.00	8.00	7.00	86.00
31	92.00	4.00	3.00	84.00
32	100.00	3.00	8.00	96.00
33	.	.	.	.

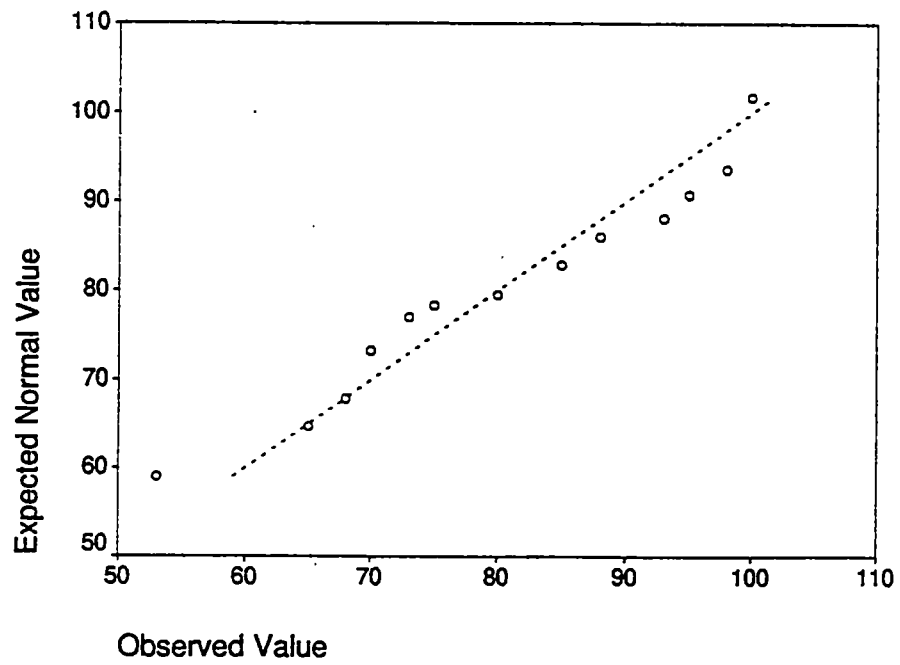
APPENDIX L

Quantile-Quantile Plots for Behavioral and Electrophysiological Measures

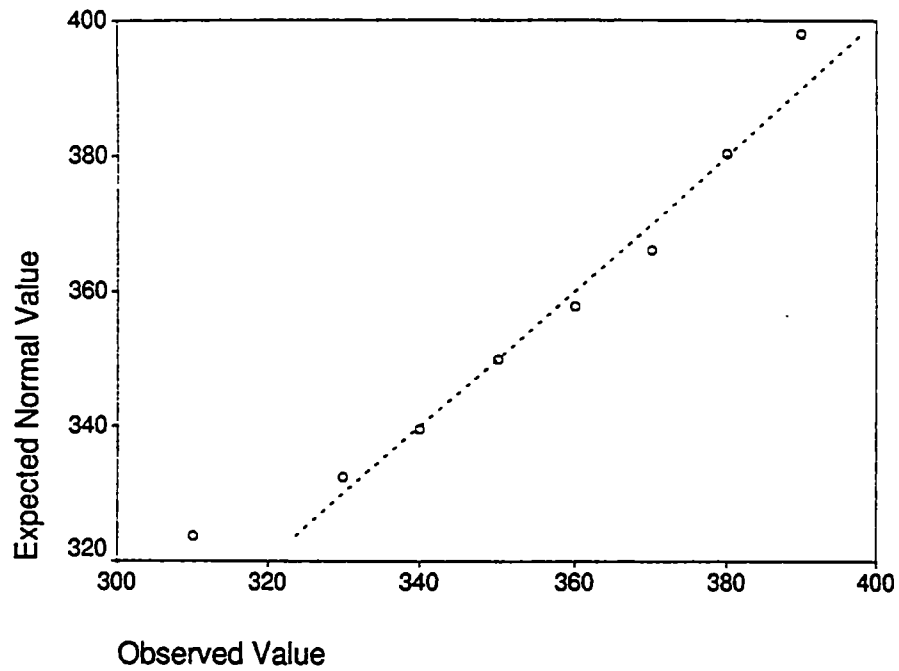
Normal Q-Q Plot of AB



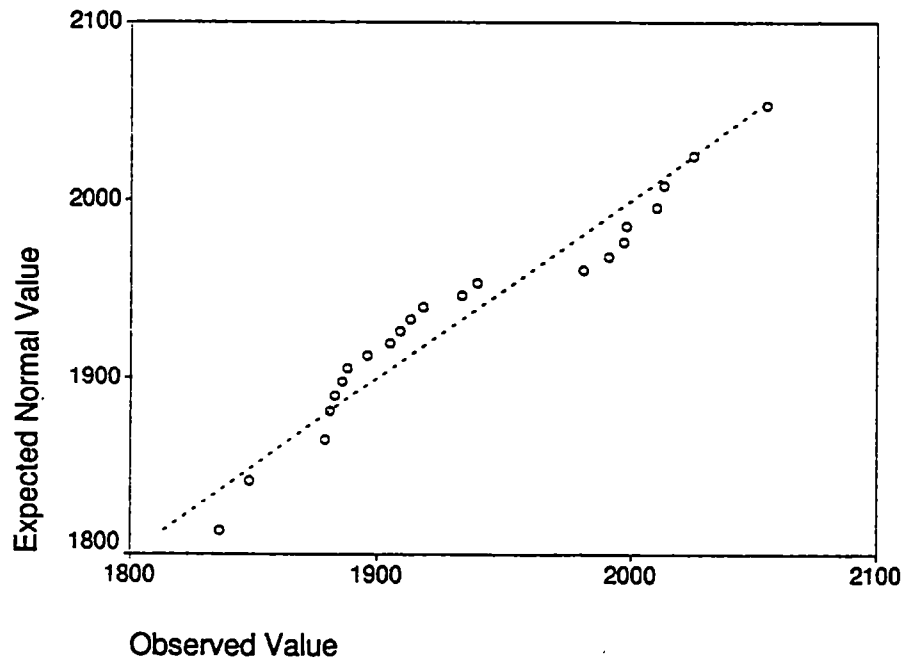
Normal Q-Q Plot of ABX



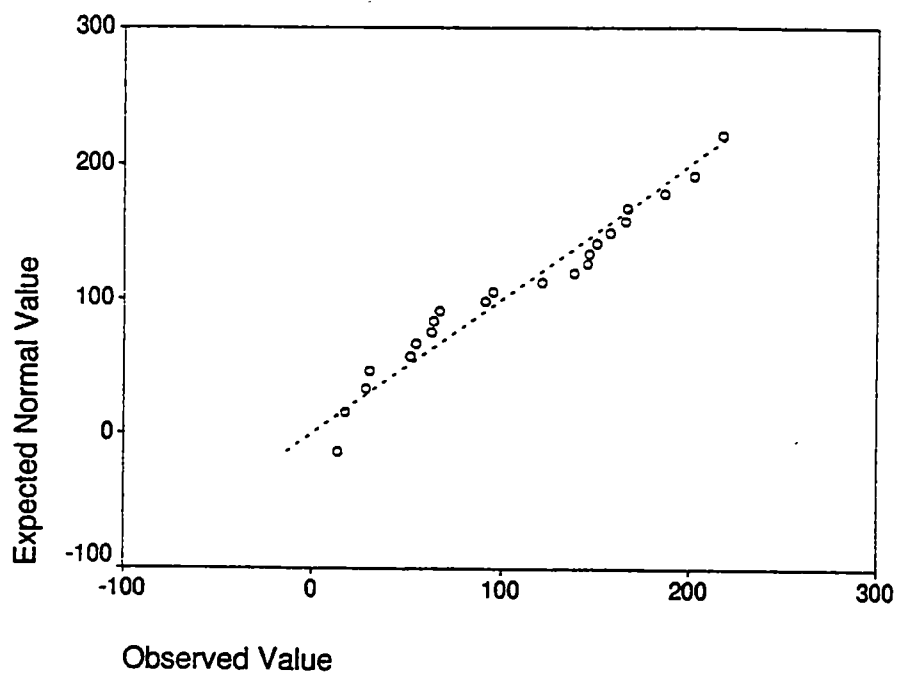
Normal Q-Q Plot of T1CZLAT



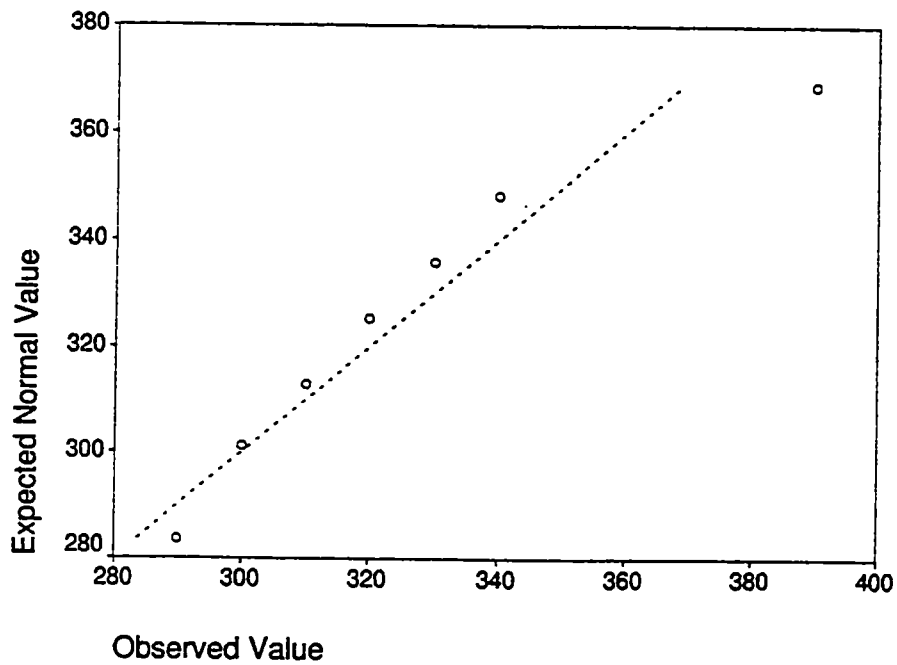
Normal Q-Q Plot of T1CZINFA

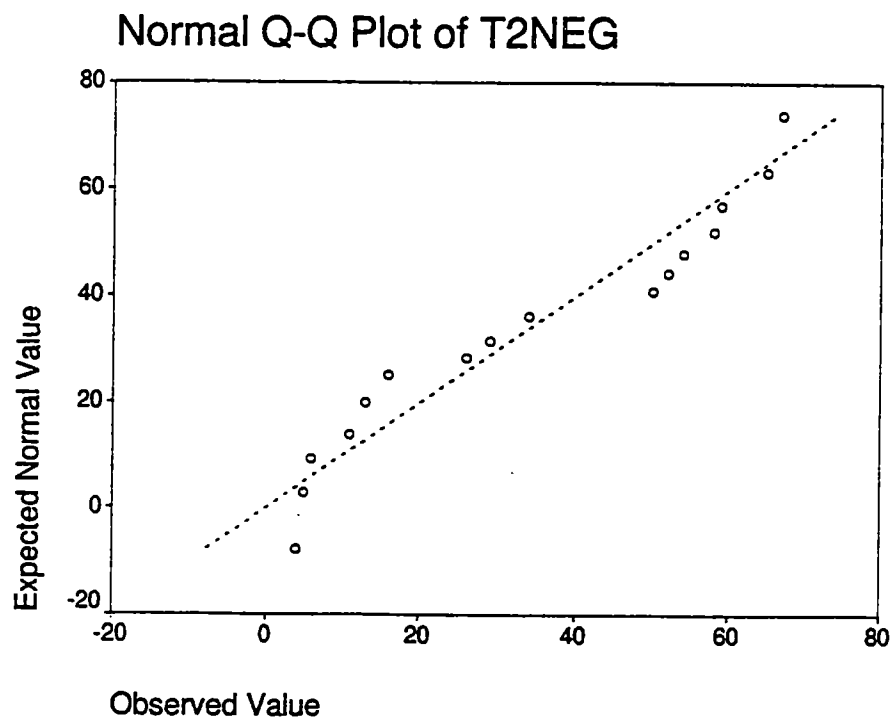
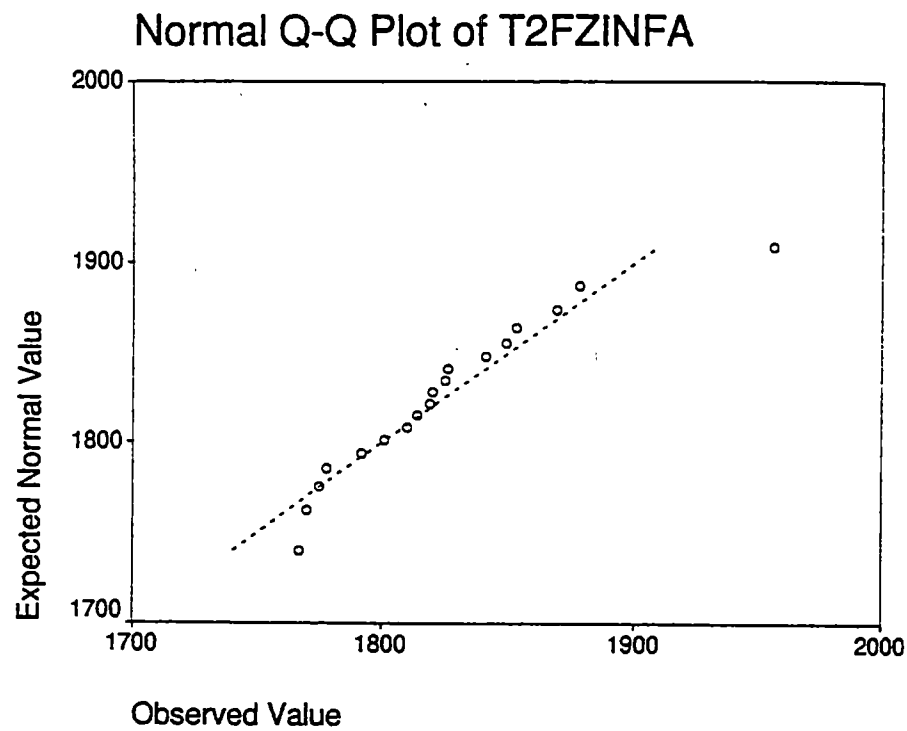


Normal Q-Q Plot of T1AMPDIF

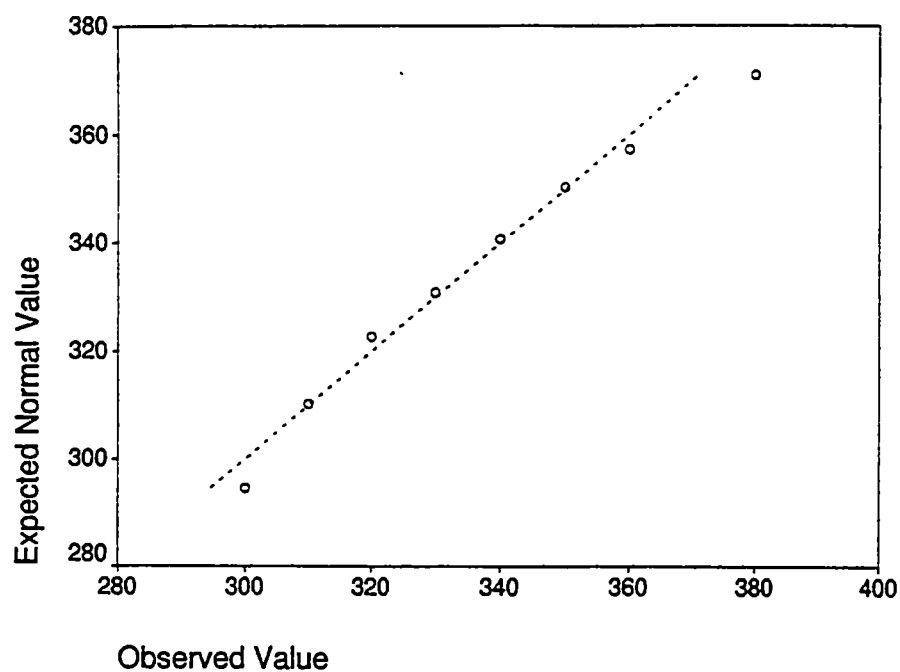


Normal Q-Q Plot of T2FZLAT

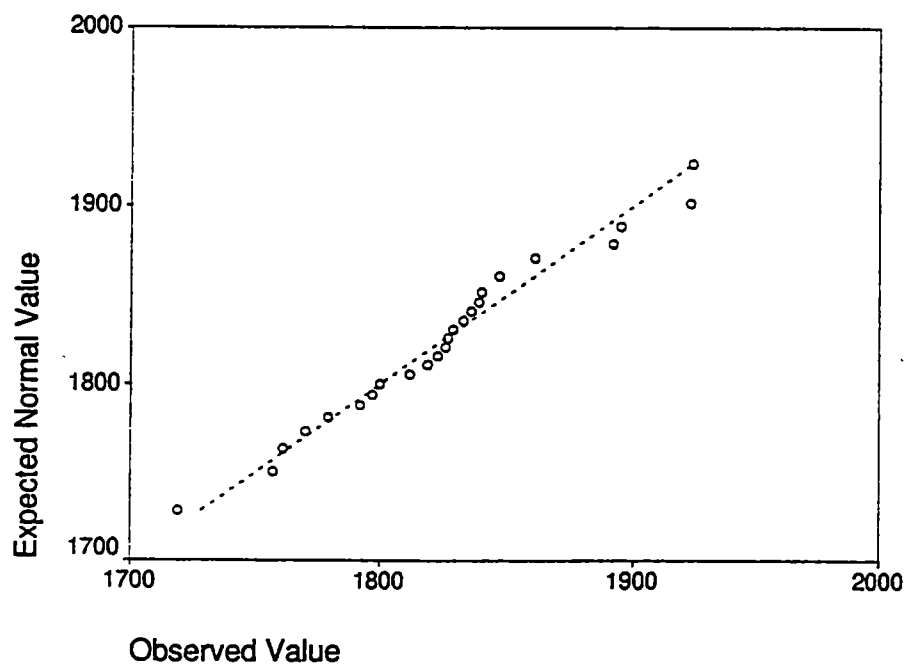




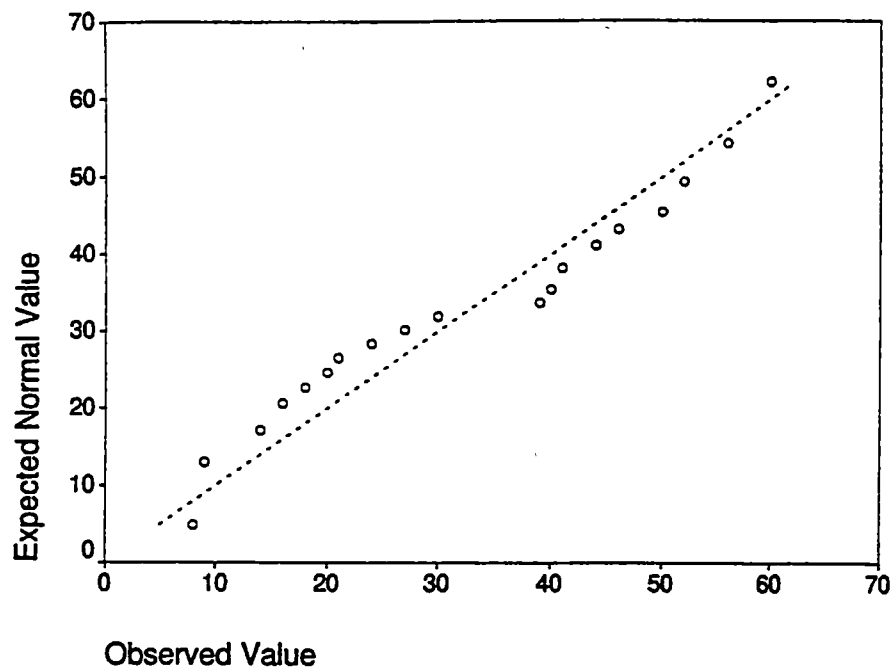
Normal Q-Q Plot of T3FZLAT



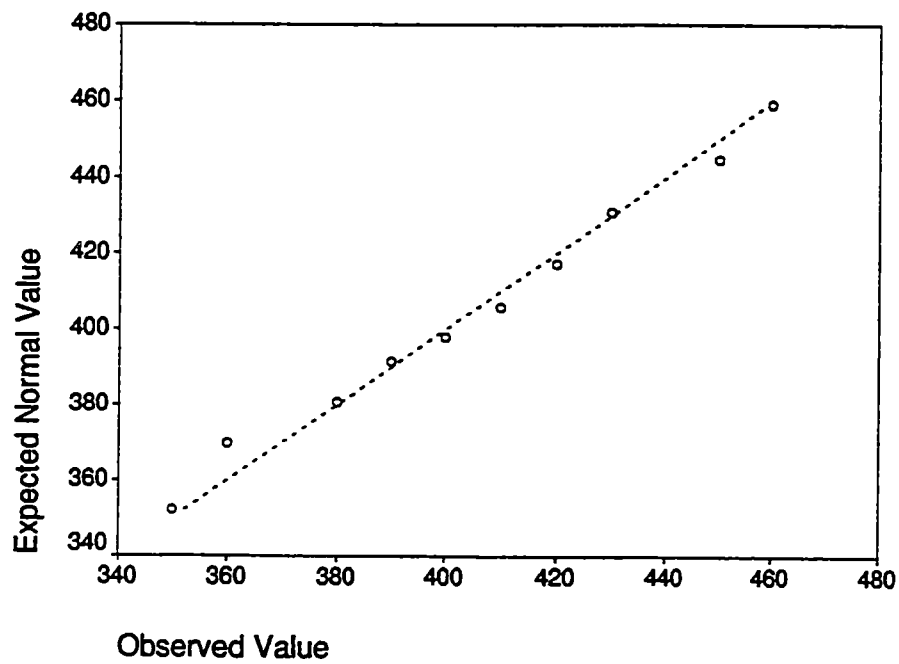
Normal Q-Q Plot of T3FZINFA



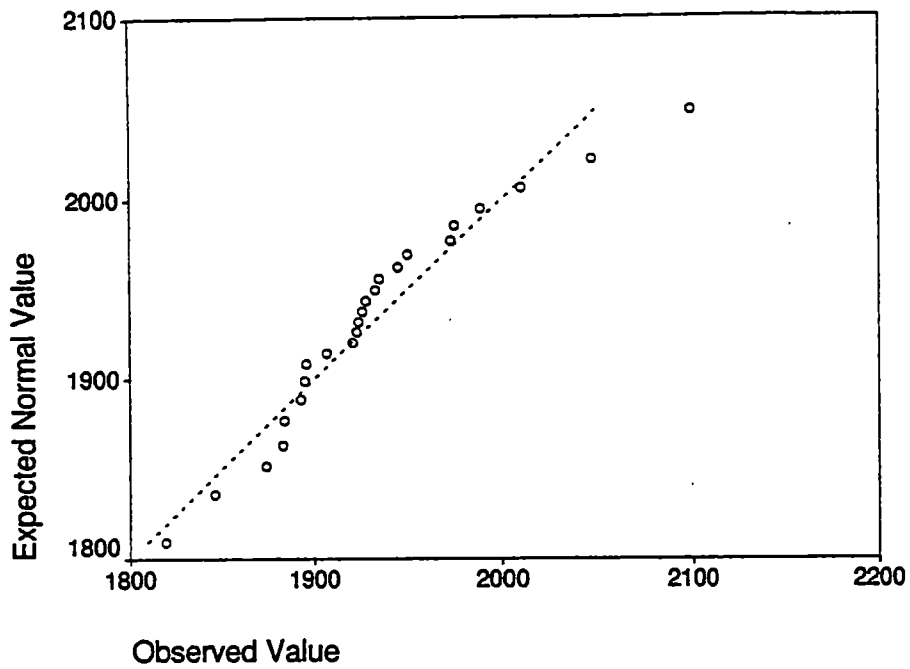
Normal Q-Q Plot of T3NEG



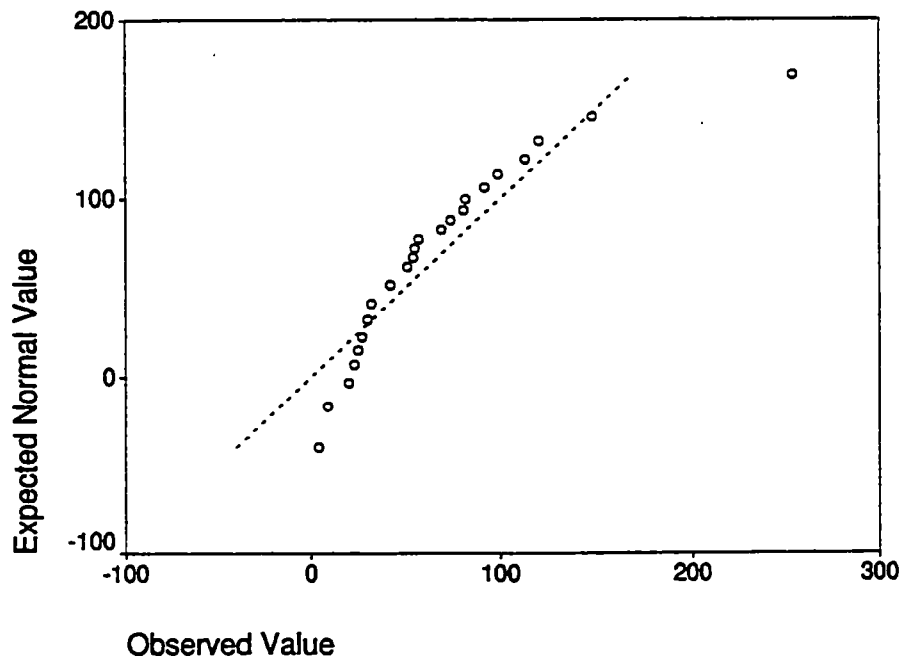
Normal Q-Q Plot of T4CZLAT



Normal Q-Q Plot of T4CZINFA

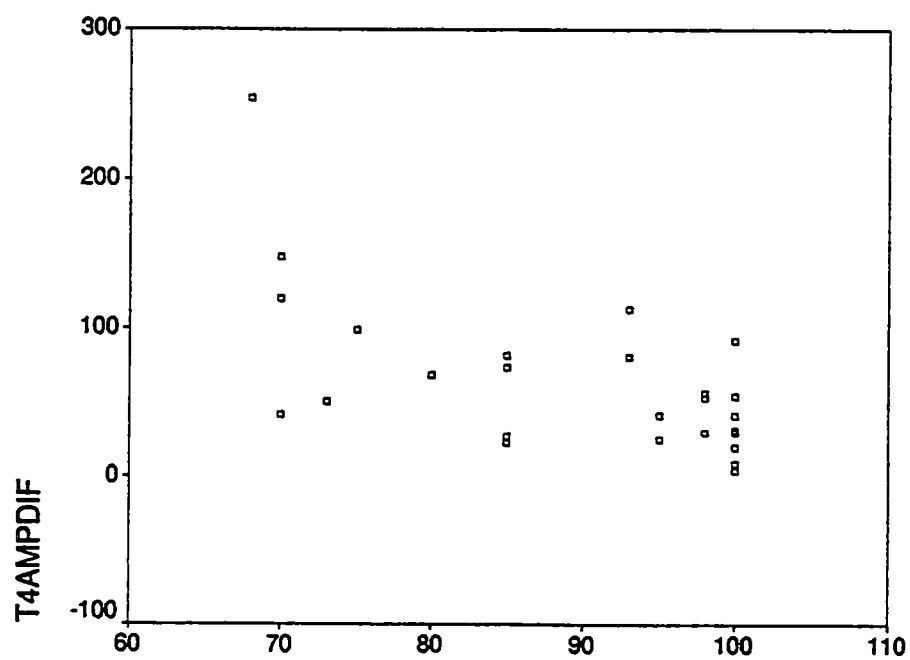
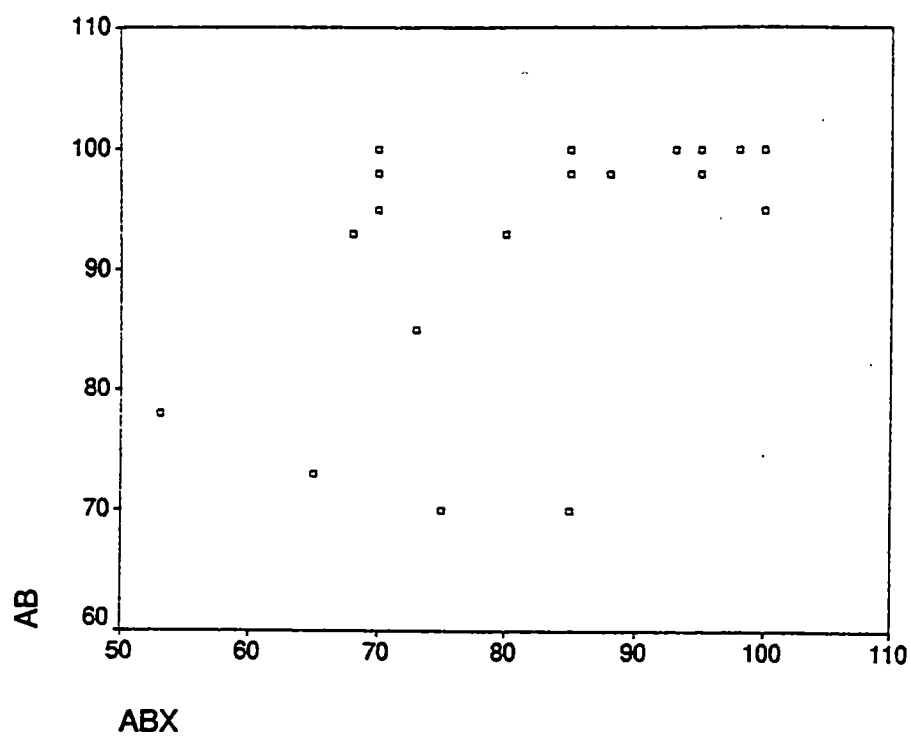


Normal Q-Q Plot of T4AMPDIF



APPENDIX M

Scatter Plots for Correlation Matrices



VITA

Cynthia Anne McCormick was born in Iowa City, Iowa on March 16, 1966. She received her Bachelor of Arts degree in Speech Pathology in March of 1988 and her Master of Arts degree in Audiology in December of 1989. She earned both degrees from the University of Tennessee, Knoxville. After working clinically for four years, she returned to UTK to pursue the doctorate in Speech and Hearing Science. Upon completing this dissertation in January, 1998, Cindy went to Dartmouth-Hitchcock Medical Center for a three month post-doctoral experience. She returned to Knoxville to receive her Ph.D. in May, 1998. Future plans include obtaining a university faculty position, with research and teaching responsibilities.