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Effects of Bilingualism, Noise, and Reverberation on Speech Perception by Listeners with Normal Hearing

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Abstract

The accurate perception of spoken English is influenced by many variables, including the listener's native language, reverberation, and background noise. Few studies of speech perception by bilingual listeners have carefully controlled for second language proficiency and even fewer have presented speech in everyday listening environments that contain noise and reverberation. In the present study, detailed language background, language proficiency information, and individual language samples were collected and the speech stimuli were presented in a variety of quiet, noisy, and reverberant listening environments.

The effects of noise and reverberation on the perception of American English monosyllabic words was examined for two groups of young listeners with normal hearing: 1) monolingual American English speakers and 2) Spanish-English bilinguals who acquired both languages prior to age 6 years, exhibited similar spoken proficiency in both languages, and spoke English without a noticeable accent. An innovative test of virtual speech perception was used to assess word recognition in two listening environments typical of everyday communication: a simulated noisy anechoic environment and a simulated noisy reverberant environment. Word recognition was also measured in quiet and in an unprocessed noisy environment. For each noisy listening environment (unprocessed, anechoic, reverberant), three signal-to-noise ratios were employed.

Results indicate that early bilingualism negatively affects perception of words presented in noisy listening environments. Significantly poorer word recognition was observed for the bilingual listeners than for the monolingual listeners in all three noisy environments and at all noise levels. Both groups exhibited similar word recognition in quiet. The results were surprising considering the high level of spoken language proficiency exhibited by all bilingual listeners. It

is often assumed that highly proficient Spanish-English speakers are equally proficient at understanding English; however, these data indicate that the speech understanding of this group may be overestimated in natural listening situations.

Introduction

Speech perception is a complicated process that can be influenced by many variables. Numerous studies have demonstrated that alteration of a speech signal by everyday factors, such as noise and reverberation, can impair the ability of a listener to correctly recognize speech (e.g., Nabelek & Mason, 1981; Crandell & Smaldino, 2000). These acoustic distortions are present to some degree in the listening environments encountered in everyday life (Helfer & Wilbur, 1990). Individual characteristics of a listener, such as language background, can further influence the perception of speech in adverse acoustic environments (Neuman & Hochberg, 1983; Nabelek, 1988; Takata & Nabelek, 1990; Helfer & Huntley, 1991). Language background should be considered in auditory research. With the increase of individuals in the United States of America learning more than one language early in life, this characteristic should be examined in detail when bilingual listeners serve as participants in speech perception studies (von Hapsburg & Peña, 2002). Findings of studies investigating the effects of adverse listening environments on communication by early bilingual participants will have important implications for speech perception in educational, occupational, and rehabilitative settings for this population.

The general effects of noise and reverberation on the perception of speech are well known. When noise is present in an acoustic environment, it masks the speech signal by obscuring the less intense portions of the signal (Helfer & Wilbur, 1990). Consonant phonemes are typically masked more than vowel phonemes because they contain less spectral energy. The result is a reduction in the redundancy of the acoustic and linguistic cues characteristic of speech. It is important to note that the extent to which noise masks a speech signal is dependent on the relationship between its overall intensity and the overall intensity of the speech signal. This relationship is referred to as the signal-to-noise ratio (SNR). Performance on speech perception tasks is best when the SNR of a listening environment is favorable (e.g., +10 dB). Performance on such tasks tends to decrease as the SNR becomes less favorable (Crandell & Smaldino, 2000).

Reverberation refers to the persistence of a sound in an enclosed environment, and is another factor that distorts speech signals (Crandell & Smaldino, 2000). Just as noise distorts a speech signal by masking it, reverberation alters the speech signal by smearing it in the temporal domain (Houtgast & Steeneken, 1973). Reverberation is usually measured in reverberation time (RT), the time required for a sound wave of a specific frequency to decay 60 dB after the signal ceases. The ability of a listener to correctly perceive speech tends to decrease as RT increases (Crandell & Smaldino, 2000). Although both noise and reverberation in isolation can degrade a speech signal, these distortions often occur simultaneously in most listening environments and are more detrimental than the sum of the component distortions (Nabalek, 1988).

Language background is a characteristic that can influence a listener's perception of speech in adverse listening environments. A review by von Hapsburg and Peña (2002) provided insight regarding participant variability in auditory research with bilingual participants. The authors stressed the importance of a better understanding of bilingualism and more strict methodology when selecting bilingual and monolingual participants for clinical speech audiometry research. Grosjean (1997) stated that the failure of many researchers to control for language background variables has contributed to the high rate of variability in results of research on bilingual participants, causing results to be contradictory and incomparable across studies.

Grosjean (1997) affirmed that obtaining a detailed language background on all participants when examining the performance of monolinguals and bilinguals in research is vital. He suggested that researchers should consider several language factors when conducting speech perception studies with bilingual listeners. Von Hapsburg and Peña (2002) organized these language factors into five areas: language status, history, competency, stability, and demand for language use. Language status refers to whether or not a participant speaks one or more languages (i.e., monolingual, bilingual, polyglot). When bilingual listeners participate in a speech perception study, it is important to state age of second language acquisition, the order in which the first (L1) and second language (L2) were acquired, and where the languages were acquired. These factors are considered language history variables. Language competency refers to the proficiency of a listener in a language. It can be examined in several domains, such as speaking, writing, reading, and listening. Questionnaires, self-rating scales, and interviews are tools often used to measure language competency. Language stability addresses whether or not a participant is in the process of acquiring a language. Finally, demand for language use describes how a specific language is used (language function) and in which types of situations a language is used by bilingual participants (language mode). The amount of time spent communicating in a language further describes the language mode of a participant.

A limited number of studies have considered the effects of such language background variables on the perception of speech. Mayo, Florentine, and Buus (1997), for example, examined the effects noise on the perception of sentences by bilingual listeners. These researchers focused on the age of acquisition of English by bilingual participants and divided the bilingual participants into 3 groups based on this variable: 1) bilingual-since-infancy (BSI), 2) bilingual-since-toddler (BST), and 3) bilingual-post-puberty (BSP). The three participants in the BSI group learned both Spanish and English beginning at birth, while the 9 participants in the BST group learned Spanish beginning at birth and acquired English as a second language by age 6 years. The BPP group included 9 participants who were native speakers of Spanish and acquired English after the age of 14 years. The monolingual group was composed of 9 participants who learned English from birth. The speech in noise test (SPIN) was administered to all participant groups. The results of this study showed that the BPP group performed poorer in noise than the BSI and BST groups, despite similar performance on a test of word recognition in quiet. In addition the results of this study indicate that although the BSI and BST groups performed significantly better than the BPP group on the SPIN test, they did not perform as well as the monolingual group.

Meador, Flege, and Mackay (2000) also examined recognition of words by bilingual individuals. In their study, the effects of age of first exposure to English and percentage use of L1 of native speakers of Italian on the number of correctly identified words in English sentences presented in noise were examined. Bilingual participants were divided into 4 groups, based on age of arrival in Canada, while the fifth group contained only English monolingual listeners. English sentences were presented at –6 dB, 0 dB, +6 dB, and +12 dB SNR. Meador et al. (2000) found that the bilingual participants who arrived in Canada earlier obtained higher scores on the word recognition tasks presented at all SNRs than the bilingual participants who arrived in Canada at later ages.

A comprehensive review of the literature reveals that studies of speech perception by listeners with diverse language backgrounds are abundant. However, the majority of studies of speech perception in adverse acoustic environments by such participants have either focused on children in the process of learning a second language or participants who acquired a second language as adults. For example, in Crandell and Smaldino’s (1996) study, two groups of children were given the task of repeating English sentences in competing noise at SNRs ranging from –6 dB to +6 dB. The first participant group included 20 English monolingual children, while the second group included 20 Spanish-English bilingual children. The bilingual children were native speakers of Spanish and began speaking English by 2 years of age. Children for whom English was a second language obtained poorer perception scores across most SNRs, as compared to scores obtained by the first participant group. The researchers suggested that children who are non-native speakers of English are more likely to experience degraded perception of English in noise. Likewise, Takata and Nabelek (1990) found that native speakers of Japanese who learned English in adulthood obtained lower English consonant recognition scores than monolingual speakers of English in noise and reverberation, despite the fact that both groups performed similarly in quiet. Native speakers of Hebrew who acquired English as adults also exhibited a decrease in word identification scores in reverberant conditions in a study of English consonant perception in reverberation by Nabelek and Donahue (1984).

Fewer studies have investigated the effect of adverse listening conditions on adult participants who acquired both their native language (L1) and a second language (L2) early in childhood and exhibited similar spoken proficiency in both languages. As stated previously, Mayo et al. (1997) examined the effect of age of second language acquisition on perception of speech in noise. The results of their study suggested that learning a second language at an early age is important for the ability to understand that language in noise. Although early bilingual participants were included in their study, only 3 of the participants acquired both Spanish and English simultaneously from birth. It is important to investigate the speech perception abilities of early bilingual individuals such as the 3 participants in the Mayo et al. (1997) BSI group, due to the increasing number of persons learning more than one language from birth and early childhood in the United States. Although it is known that children and adults learning a second language exhibit difficulties understanding speech in adverse listening conditions, less is known about performance in adverse listening environments of bilingual adult listeners who acquired two languages in early childhood (Crandell & Smaldino, 1996; Takata & Nabalek, 1990; Nabalek & Donahue, 1984).

According to the United States Census, the total resident population of the United States in the year 2000 was 281 million. A current population report by the U.S. Census Bureau (Therrien & Ramirez, 2000) stated that 32.8 million Hispanic individuals currently reside in the United States. This represented approximately 12.0 percent of the total population of the nation and included people from Mexican, Central American, South American, Puerto Rican, Cuban, and other Hispanic origins. The Hispanic population is the fastest growing minority group in the United States and is projected to become the largest minority group in the future. According to data on language use from the 1990 U.S. Census, 31.8 million people out of a total population of 230 million spoke a language other than English at home. Of the 50 languages other than English with the greatest number of speakers in the United States in 1990, Spanish was ranked first, with 17 million speakers. Of those, 9 million reported that they spoke English very well. Eleven years later, a 2001 U.S. Census Bureau Supplementary Survey Profile on language use reported that 46 million individuals spoke a language other than English at home. Again, Spanish was ranked first, of the 50 languages other than English, with 27.9 million speakers. One would speculate that a proportional increase in individuals who speak both Spanish and English will continue, as the Hispanic population in the United States continues to grow.

The purpose of this study was to examine the effects of noise and reverberation on the perception of American English speech by adult early Spanish-English bilingual participants with normal hearing and similar linguistic profiles. A test of virtual speech intelligibility (Koehnke & Besing, 1996) was used, in order to assess performance in listening environments typical of everyday communication. Bilingual listeners were selected by obtaining information about various aspects of their language background. Conversational speech samples were obtained to ensure that others would perceive the bilingual participants as highly proficient speakers of English.

Methods

Participants

The speech perception of two groups of young listeners with normal hearing was assessed in quiet and in the presence of noise and/or reverberation: 1) monolingual American English speakers and 2) early Spanish-English bilingual speakers. All participants were between the age of 18 and 35 years. All participants had normal hearing, defined as pure tone air conduction thresholds of 20 dB HL or better from 250 to 6000 Hz and air-bone gaps of 10 dB or less, bilaterally. All participants had normal tympanograms, with ear canal volume measures between 0.5 and 2.5 ml, compliance measures between 0.2 to 1.8 ml, and pressure measures between –100 to 100 daPa. The monolingual group included 15 participants (mean age = 25.3 years), while the bilingual group included 12 participants (mean age = 24.7 years). All monolingual participants were native speakers of American English. All bilingual participants were native speakers of Spanish and acquired American English in early childhood (before the age of 6 years). This age was chosen because Mayo et al. (1997) found that the BSI and BST groups in their study performed similarly on the SPIN test. Listeners in their BST group had learned English as a second language before the age of 6 years. All participants were recruited from the students, faculty, and staff of the University of South Florida’s Tampa Campus and the surrounding community.

Instrumentation

A Grason-Stadler GSI-61 audiometer, Panasonic CD player, TDH-49 headphones, and Tele-acoustics double-walled sound-treated booth was used for the hearing evaluation and for the administration of the speech perception tests. A Grason-Stadler Tymp Star was used to assess middle ear function. For the speech perception tests, several compact disk (CD) recordings of monosyllabic words were used. A custom compact disk (CD) recording of 200 CID W-22 monosyllabic words (4 lists of 50 phonetically balanced words) developed locally by the experimenter was used to measure binaural speech perception in quiet and in the presence of speech noise. Speech perception was measured binaurally at SNRs of +2, 0, and –6 dB. This condition was referred to as the Unprocessed W-22 test.

The Speech Intelligibility Gain – Anechoic (SIG-A) and the Speech Intelligibility Gain – Reverberant (SIG-R) virtual audiometry tests (Koehnke & Besing, 1996) were used to assess binaural speech perception in two simulated listening environments: 1) an anechoic environment with background noise and 2) a reverberant environment with background noise. The SIG-A test was administered at the following SNRs: +2 dB, 0 dB, and –2 dB. The SIG-R test was administered at the following SNRs: +4 dB, +2 dB, and 0 dB. These SNRs were suggested by the developers of the SIG tests (Drs. Janet Koehnke and Joan Besing) as challenging for young listeners with normal hearing in each environment and were based on the pilot studies of Drs. Koehnke and Besing (Dethloff, et al., 1998; Besing, et al. 2001). In both environments, the speech signal (randomly presented words from the CID W-22 word lists) and noise signal (speech spectrum noise) were presented from simulated locations approximately one meter from the listener's head at 0° azimuth. More detailed information about the SIG-A and SIG-R tests can be found in Koehnke and Besing (1996). For all speech perception tests, the intensity level of the speech stimuli remained fixed at 50 dB HL and the intensity of the noise varied to achieve the various SNRs.

All participants completed a participant questionnaire that provided detailed information concerning their language background (Appendix A), as suggested by Grosjean (1997). The questionnaire included 15 questions regarding language background and five questions regarding hearing history. The 15 questions in the language background portion of the questionnaire provided information regarding the language status, language history, language competency, and language mode of all bilingual participants. A TASCAM DA-P1 digital audio tape recorder was used to record conversational language samples and citation speech of all participants.

Procedure

All potential participants completed the participant questionnaire prior to audiometric testing. Selected information from this questionnaire is presented in Table 1 for the bilingual participants and in Table 2 for the monolingual participants.

Table 1: Language background and age descriptors for bilingual participants.

Subject	Age	L1	Age L1	Age L2	Most Fluent	% L1	%L2	L1 Accent	L2 Accent	Birth Place
B001	26	Spanish	Birth	4	English	50	50	No	No	Cuba
B002	24	Spanish	Birth	3	English	25	75	No	No	NM, USA
B003	31	Spanish	3	3	English	25	75	No	No	IL, USA
B004	19	Both	3	3	Both	50	50	No	No	Okinawa, Japan
B005	26	Both	3	3	English	25	75	No	No	NJ, USA
B006	24	Both	3	3	Both	25	75	No	No	Puerto Rico
B007	21	Both	2.5	2.5	Both	50	50	No	No	Panama
B008	18	Both	2.5	2.5	English	50	50	No	No	NC, USA
B009	24	Spanish	Birth	6	English	25	75	No	No	Cuba
B010	30	Both	3	3	Both	25	75	No	No	AL, USA
B011	29	Spanish	2	5	English	25	75	No	No	GA, USA
B012	24	Spanish	Birth	5	Both	50	50	No	No	Puerto Rico

Table 2: Language background and age descriptors for monolingual participants.

Subject	Age	L1	% L1	L1 Accent	Birth Place
M001	27	English	100	No	Jamaica
M002	26	English	100	No	FL, USA
M003	25	English	100	No	NJ, USA
M004	23	English	100	No	FL, USA
M005	30	English	100	No	FL, USA
M006	31	English	100	No	KY, USA
M007	23	English	100	No	PA, USA
M008	22	English	100	No	CA, USA
M009	24	English	100	No	VA, USA
M010	24	English	100	No	FL, USA
M011	22	English	100	No	FL, USA
M012	24	English	100	No	FL, USA
M013	28	English	100	No	NY, USA
M014	24	English	100	No	PA, USA
M015	26	English	100	No	FL, USA

All potential participants received a standard pure-tone hearing screening, a test of speech recognition in quiet, a test of word recognition in quiet (using the custom W-22 CD), and tympanometry. All participants who passed the aforementioned criteria for normal hearing were audio taped while engaging in conversation in English and while repeating the Harvard sentences (Appendix B). Bilingual participants were also audio taped while engaging in conversation in Spanish and repeating Spanish Auditec® paired comparison sentences (Appendix C). The Harvard Sentences and the Auditec® paired comparison sentences in Spanish were presented via the Panasonic CD player and TDH-49 headphones. The experimenter, who was bilingual (Spanish-English), elicited the conversational samples by asking the following question: "what are your plans for the future?" and "¿cuáles son sus planes para el futuro?"

Two certified speech language pathologists from the Communication Disorders Center at the University of South Florida evaluated the audio taped speech samples using the Accent Rating Form (Appendix E). One of the speech language pathologists was a monolingual native speaker of American English, while the other was a bilingual Spanish-English speaker. Fifteen of the 18 potential monolingual participants were judged to have non-accented speech in conversational American English. Additionally, 12 of the 14 potential bilingual participants were judged to have non-accented speech in both conversational English and conversational Spanish. Non-accented conversational speech for both languages was defined as a score between 1 and 2 on the Accent Rating Form. Only the 15 monolingual participants judged to be fluent in English and to have no noticeable regional accent during the speech sample were allowed to participate further in the study. Likewise, only the 12 bilingual participants judged to be fluent in conversational Spanish and to have no noticeable regional accent while speaking English were allowed to participate further in the study.

Each listener's task during all speech perception tests (Unprocessed W-22, SIG-A, and SIG-R) was to repeat the monosyllabic words in the presence of noise. The listeners were given a standard set of verbal instructions. Each participant was instructed to listen carefully and repeat the word. They were told to guess, if necessary. The noise began before the presentation of each word. Practice trials or training were not provided. The experimenter recorded each participant's response on a data sheet to be scored following the experimental session. The speech perception tests were presented in the following order for all participants: Unprocessed W-22 tests, SIG-A tests, and SIG-R tests.

The number of correctly repeated words was recorded at several SNRs using the Unprocessed W-22, SIG-A, and SIG-R tests. The Unprocessed W-22 test and the SIG-A and SIG-R tests were presented at the SNRs listed previously. List presentation was counterbalanced across participants using a modified Latin Square Design (Maxwell & Satake, 1997). Thus, all lists were presented an equal number of times at each SNR within a processing condition and each listener heard each list only at a single SNR. The individual SNRs within each test were presented in an order of least to greatest difficulty (most favorable to least favorable SNR). A list of 25 words was presented at each SNR.

Results

All participants obtained scores between 96% and 100% on the word recognition test in quiet. As shown in Figure 1, the monolingual group repeated more words correctly than the early bilingual group at all three SNRs for the Unprocessed W-22 test. Performance for both participant groups was poorest at the –6 dB SNR and best at the 0 dB SNR.

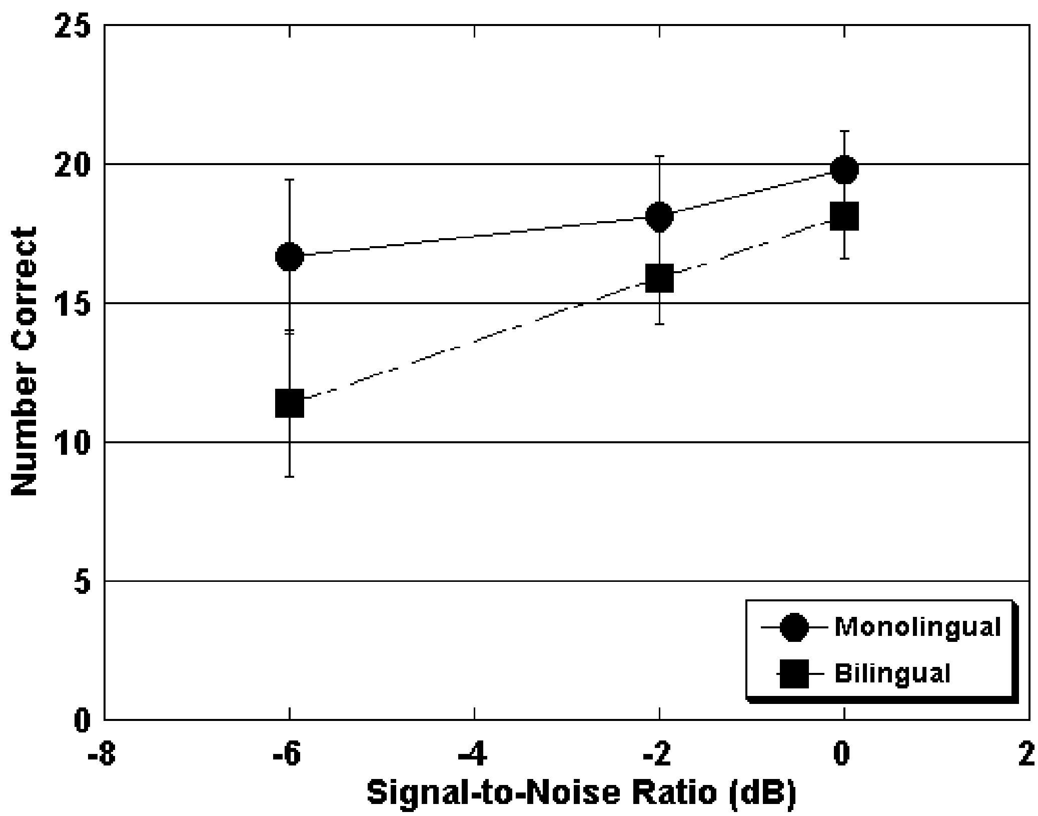

Figure 1. Number of unprocessed monosyllabic words repeated correctly by monolingual (filled circles) and bilingual (filled squares) listeners at three SNRs (-6, -2, and 0 dB). Error bars represent one standard deviation from the mean.

A two-way repeated measures analysis of variance (ANOVA) revealed a significant main effect of group [$F(1,25) = 27.57$, $p = 0.00002$] and a significant main effect of SNR [$F(2,50) =$

44.67, p < 0.00001]. The interaction between group and SNR was not significant (p > 0.05). A Tukey HSD *post-hoc* analysis of the main effect of SNR revealed that performance at all SNRs differed significantly from each other (p < 0.01).

Figure 2 illustrates performance for the simulated anechoic environment (SIG-A test). Performance for both participant groups was poorest at the –2 dB SNR and best at the +2 dB SNR. The monolingual group obtained higher scores than the early bilingual group at all SNRs.

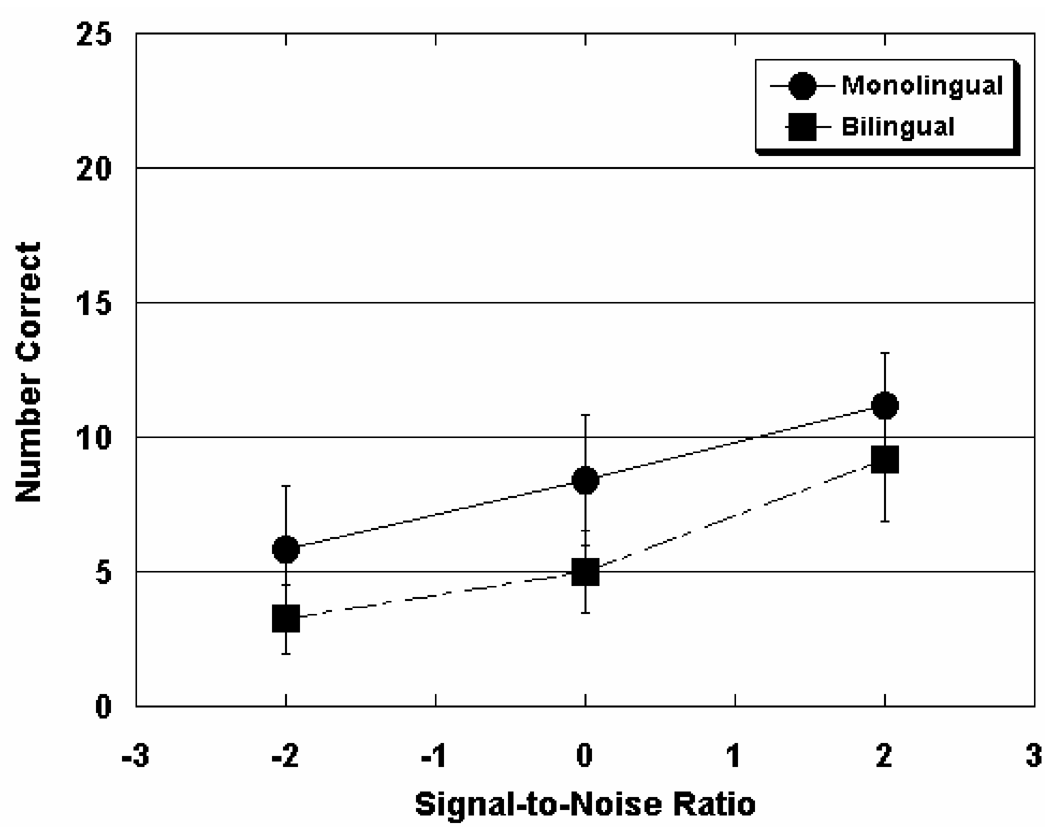

Figure 2. Number of monosyllabic words repeated correctly by monolingual (filled circles) and bilingual (filled squares) listeners across SNRs for the simulated anechoic (SIG-A) environment. Error bars represent one standard deviation from the mean.

A two-way repeated measures ANOVA revealed a significant main effect of group [F(1,25) = 22.19, p = 0.00008] and a significant main effect of SNR [F(2,50) = 61.26, p < 0.00001]. The interaction between group and SNR was not significant (p > 0.05). A Tukey HSD *post-hoc* analysis of the main effect of SNR revealed that performance at all SNRs differed significantly from each other ($p < 0.001$).

Performance in the simulated reverberant environment (SIG-R test), as shown by Figure 3, followed a pattern similar to that of the Unprocessed W-22 and SIG-A tests. The monolingual group obtained higher scores than the early bilingual group at all three SNRs on the SIG-R test; however, the group difference for the +2 dB SNR was minimal. Performance for both participant groups was highest at the +4 dB SNR and lowest at the 0 dB SNR.

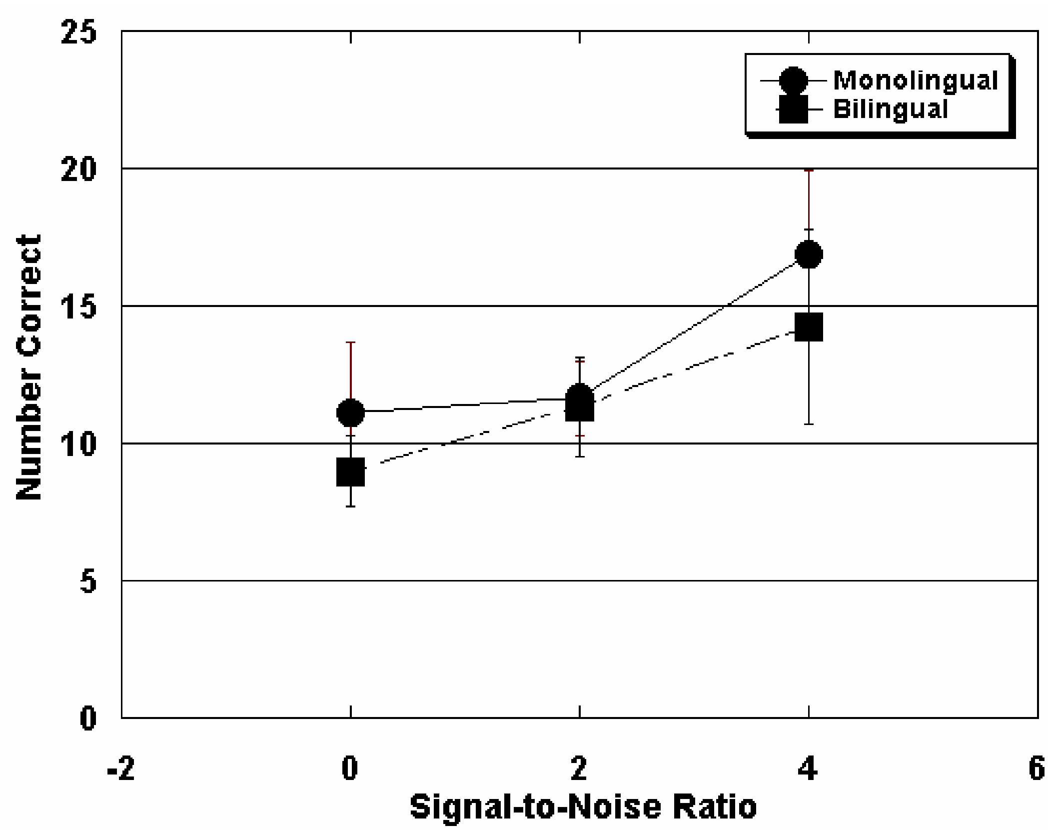

Figure 3. Number of monosyllabic words repeated correctly by monolingual (filled circles) and bilingual (filled squares) listeners across SNRs for the simulated reverberant (SIG-R) environment. Error bars represent one standard deviation from the mean.

A two-way repeated measures ANOVA revealed a significant main effect of group [$F(1,25) = 7.53$, $p = 0.011$] and a significant main effect of SNR [$F(2,50) = 38.78$, $p < 0.00001$].

The interaction between group and SNR was not significant ($p > 0.05$). A Tukey HSD *post-hoc* analysis of the main effect of SNR revealed that performance differed significantly for all SNRs ($p < 0.0001$) except +2 vs. +4 dB SNR.

To compare the performance of the monolingual and early bilingual group across listening conditions at the 0 dB SNR, a two-way repeated measures ANOVA was performed. The main effect of group was significant [$F(1,25) = 31.36$, $p < 0.000008$]. The main effect of listening condition was also significant [$F(2,50) = 270.75$, $p < 0.00001$]. The interaction between group and listening condition was not significant ($p > 0.05$). A Tukey HSD *post-hoc* analysis of the main effect of listening condition revealed that performance for each listening condition significantly differed from that of the other two listening conditions ($p < 0.001$). To illustrate the differences among the groups, the number of correct responses was plotted as a function of listening condition in Figure 4. The figure shows poorer performance by the early bilingual group as compared to the monolingual group across all test conditions. Both listener groups showed best performance in the Unprocessed condition and poorest performance in the Anechoic condition.

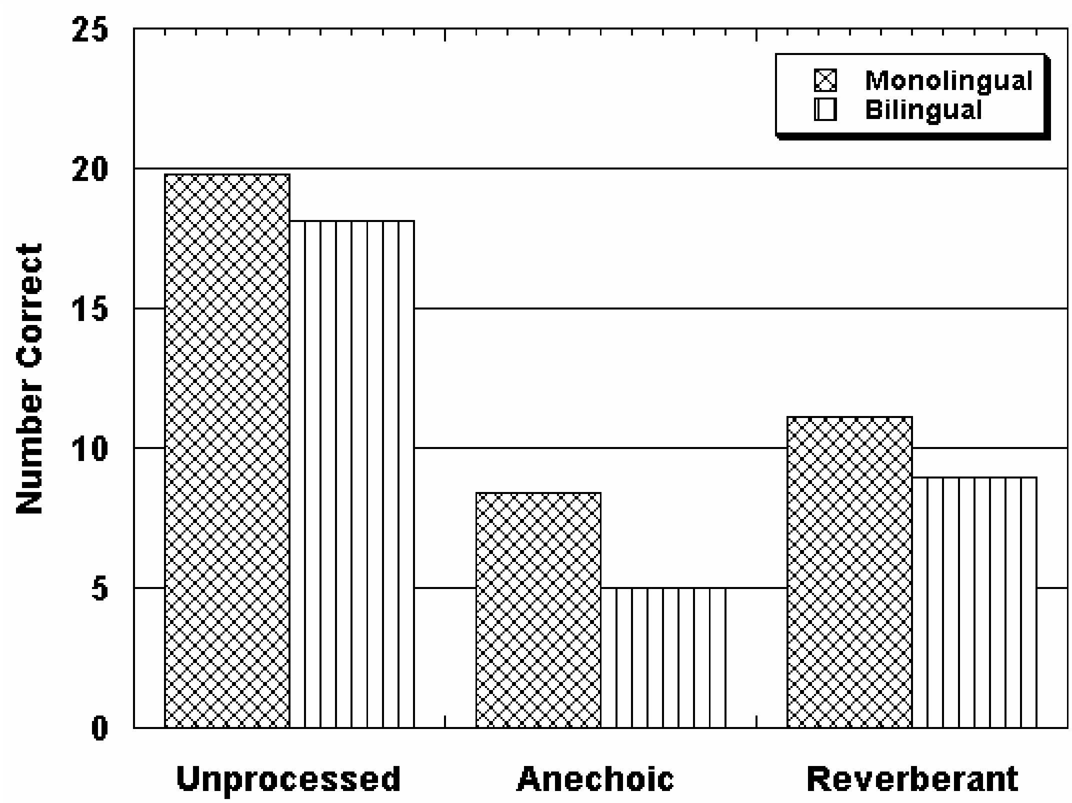

Figure 4. Number of monosyllabic words repeated correctly by monolingual (diamond pattern) and bilingual (vertical pattern) listeners for 0 dB SNR across the three listening conditions.

A three-way repeated measures ANOVA was completed to evaluate the interactions between participant groups in the simulated anechoic and reverberant listening conditions at SNRs of 0 dB and + 2 dB. The interaction between listening condition and SNR was significant [$F(1,25) = 6.11$, $p = 0.02$]. A Tukey HSD post-hoc analysis of the interaction revealed a significant effect of environment at the 0 dB SNR ($p = 0.0002$). The effect of environment at the

+ 2 dB SNR was not significant (p = 0.135).

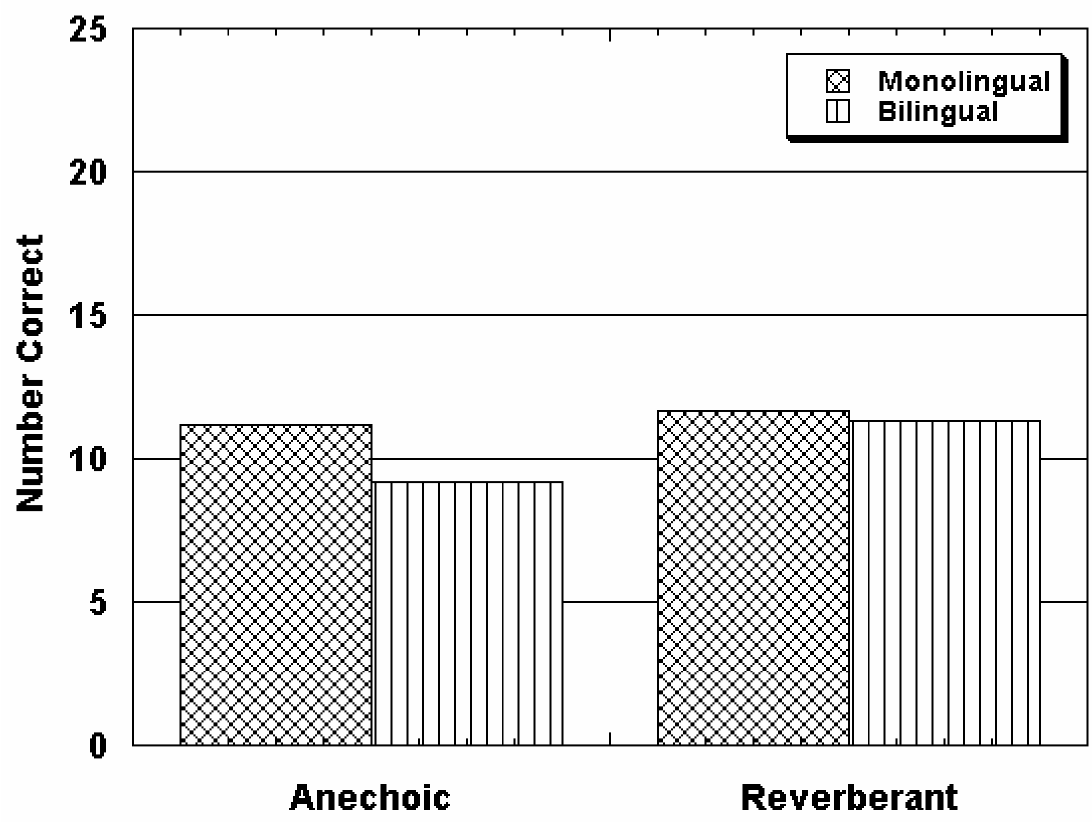

Figure 5. Number of monosyllabic words repeated correctly by monolingual (diamond pattern) and bilingual (vertical pattern) listeners at 2 dB SNR the simulated anechoic (SIG-A) and simulated reverberant (SIG-R) environments.

Discussion

The purpose of this study was to examine the effects of noise and reverberation on the perception of American English speech by adult early Spanish-English bilingual participants with normal hearing and similar linguistic profiles. Performance of the early Spanish-English bilingual participant group on tests of speech perception was compared to that of the monolingual participant group. The results of this study indicate that the factor of early bilingualism negatively affected recognition of words that were presented in background noise and in simulated reverberation. Significantly poorer performance was measured for the early bilingual listeners than for the monolingual listeners in all listening conditions and at all SNRs. All participants obtained similar scores on the word recognition test in quiet (between 96-100%). While previous studies have suggested that early bilinguals perform more like monolinguals on tests of speech perception in noise, the present study suggests otherwise (von Hapsburg & Peña, 2002).

Several factors could contribute to the large significant effects between listener group across the speech perception tests administered in this study. First, a more strict methodology than typically used in auditory bilingual research was used in order to select bilingual participants for this study. Measures were taken to ensure that the linguistic profiles of the participants were as similar as possible, from age of acquisition of L1 and L2 to amount of use and perceived proficiency in both languages. Speech samples were also collected and evaluated to ensure that the bilingual participants were fluent in conversational Spanish, although dialect of Spanish was not controlled for. Although the bilingual listeners included in this study are most representative of the Spanish-English bilinguals living in many areas of the United States of America today, they are not representative of the bilingual populations that have been the focus of previous speech perception studies. The bilingual listeners included in this study were of Puerto Rican, Cuban, Panamanian, or Columbian descent and lived in the Southeastern area of the United States of America the majority of their lives. They acquired both American English and Spanish in early childhood and were considered to be fluent in both languages. All listeners in this study were judged to have no regional dialect in English. Thus, participants in both groups were perceived to be highly proficient speakers of English.

Furthermore, the early bilingual participants in this study were young adults (mean age = 24.7 years). As mentioned previously in this paper, the majority of studies on perception of L2 have included participants that were either children in the process of acquiring L2 or listeners who had acquired L2 as adults. The bilingual listeners selected for this study were considered to be stable in both American English and Spanish (i.e., they were not in the process of acquiring either language). In general, the bilingual participants reported that they had acquired both languages before the age of 6 years. All participants were educated in American English. Amount of English use (spoken) was reported as between 25% to 50% during a 24-hour period. Amount of Spanish use (spoken) was reported as between 50 to 75% during a 24-hour period, as the bilingual participants either studied or worked in American English speaking environments during most of their day. All bilingual participants stated that they understood both languages equally.

Another factor that could contribute to the difference in performance between groups in this study was the type of test used. The SIG-A and SIG-R tests were designed as simulations of noisy anechoic and reverberant environments. These tests were chosen in an effort to examine the recognition of words in environments more representative of everyday listening situations. Such tests have not been used previously in bilingual research. The technology used to create the virtual listening environment for the SIG tests eliminated difficulties typical of measuring speech intelligibility in the sound field. Such difficulties include calibration, replicating speaker placement, control of head movements, control and measurement of reverberation and background noise, and the interaction between stimuli and test room. Thus, the examiner was able to focus on performance of the participants without having to consider the possible influence of these factors on the results obtained.

The speech stimulus of the SIG tests is an additional factor that may have influenced performance of the listeners on the speech perception tests in this study. It is known that linguistic context can influence the perception of speech. Words in isolation are less likely to be identified correctly than words in sentence context (O'Neil, 1957; Boothroyd, 1985). In this study, monosyllabic words were presented in noise and simulated anechoic and reverberant listening conditions. This may have increased the difficulty of the speech perception task, since no linguistic context was available to the listener. In contrast, other studies of speech perception in noise by bilingual listeners or listeners for whom English is a second language have used sentences as the speech stimulus. Thus, linguistic context may have contributed to the correct identification of the speech stimulus in noise (Mayo, et al., 1997; Crandell & Smaldino, 1996).

An unexpected result of this study was the poorer performance on the SIG-A tests, as compared to the performance on the SIG-R tests. Typically, speech perception in reverberation and noise is poorer than in a noise only condition. It was predicted for both groups to perform better in the simulated Anechoic environment than in the simulated Reverberant environment, as shown by the results of a pilot study that evaluated the performance of listeners with normal and impaired hearing on the SIG-A and SIG-R tests (Besing, et al., 2001). The results of the present study did not support this expectation, nor can we explain these results. However, it is possible that better performance on the SIG-R tests was due to an order effect, since the SIG-R tests were always the last tests administered and the participants may have been the most practiced at the task by the end of the testing sequence.

Results of the current study can be applied to several contexts. For example, various researchers have suggested modifications of room acoustics for children learning English as a second language (Picard & Bradley, 2001; Crandell & Smaldino, 2000) in order to decrease reverberation time and noise present in the educational environment. Such modifications would also be beneficial for early bilingual students in post-secondary educational settings, such as large auditoriums typically used on college campuses, and occupational situations. Nelson & Soli (2000) stated that reverberation times between 0.2 to 0.6 seconds and a + 15 dB SNR are considered favorable for understanding speech in a classroom. The range of reverberation times typically reported for classrooms is from 0.4 to 1.2 seconds, while the range of SNRs reported for classroom settings is between -7 dB to +5 dB (Crandell & Smaldino, 2000). It should be noted that the SNRs used for both SIG tests (–2 to +4) were comparable to those found in typical classroom environments. Large halls or cathedrals tend to be highly reverberant rooms, with reverberation times greater than 1 second (Nelson & Soli, 2000). The reverberation time of the SIG-R tests used in this study was 0.25 to 0.4 seconds. This reverberation time is shorter, and therefore more favorable, than those found in typical classroom settings. Therefore, one would expect the speech perception of early bilingual listeners with normal hearing in a typical reverberant classroom to be overestimated by the results of this study.

Additionally, the effects of noise and reverberation on older early bilinguals or early bilinguals with hearing loss have not been investigated. It is known that age and hearing loss further impair speech perception in adverse listening environments. Even in moderate amounts of noise, young listeners with normal hearing may only experience a slight decrease in speech perception ability (Nabelek & Pickett, 1974). However, the results of a study by Nabelek and Robinson (1982) indicated that the perception of sentences in reverberation becomes more challenging as adults age. They found that older listeners with normal hearing in their study required higher intensity levels of a speech stimulus in order to perform as well as young adults with normal hearing.

Furthermore, Helfer and Wilber (1990) suggested that noise and reverberation affect the speech intelligibility of individuals with hearing loss more adversely than those with normal hearing. The findings of Nabelek & Pickett (1974) also support this. They found that the speech perception abilities of participants with sensorineural hearing loss were affected more in noise and reverberation than those of participants with normal hearing.

From the data outlined above, one might hypothesize that aging and hearing loss would affect older early bilinguals more negatively than older monolinguals. Further studies in this area are needed as the findings of such studies would provide information that may prove helpful when selecting amplification for older early bilinguals with hearing loss. Use of FM systems, directional microphone technology, and noise reduction technology may also be beneficial options to consider for such individuals. In addition, this information would encourage audiologists to further stress the importance of communication strategies when treating older early bilingual patients with and without hearing loss.

Future research concerning speech perception by bilingual listeners should continue to follow the methodological suggestions proposed by Grosjean (1997) to increase replicability within and across studies and applicability of results for different types of bilingual individuals. This study investigated the general effects of noise and reverberation on perception of words by adult early bilinguals with normal hearing by comparing their performance to that of American English monolinguals. Although a detailed language background was obtained in order to ensure as much similarity in linguistic profiles as possible, this study did not focus on the relationships between individual language background factors on the perception of speech. Mayo et al. (1997) has investigated the relation between age of L2 acquisition and the perception of sentences in noise. The relation between speech perception in adverse listening environments and other language background variables, such as language proficiency, demand for use, and amount of use in everyday should be further investigated.

The present study adds to the literature by using stricter methodology to select bilingual participants. Early bilingual participants with similar language backgrounds were chosen. Specific information regarding their language profiles was stated and presented in table form. In addition, allowing only young listeners with normal hearing to participate in the study eliminated factors such as age and hearing loss that could have confounded the results obtained.

The results of this study are representative of speech perception performance in noise and reverberation by early bilingual listeners that fit the criteria aforementioned in this paper. Findings are limited to this group of bilingual listeners and should be applied in their educational, occupational, and rehabilitative settings in order to increase their perception of speech in the presence of acoustic distortions.

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Appendix A

The Effects of Noise, Reverberation, and Bilingualism (Spanish/English) on Speech Perception

Participant Questionnaire

1. Are you a Spanish/English bilingual? Yes ____ No ____

* ***If you checked "no", go to question #12*** *

2. Which language did you learn first? ________________________________
   - ❑ Spanish
   - ❑ English

3. At what age did you learn English? ________________________________
4. At what age did you learn Spanish? ________________________________
5. Where did you learn English?
   - ❑ At home
   - ❑ At school
   - ❑ At work
   - ❑ Other: ____

6. Which language are you most fluent in (i.e. which language do feel you ***speak*** best)?
   - ❑ Spanish
   - ❑ English
   - ❑ I am equally fluent in both

7. Which language do you ***understand*** the best?
   - ❑ Spanish
   - ❑ English
   - ❑ I understand both equally

8. What percentage of the time, during a 24-hour period, do speak Spanish?
   - ❑ 10% of the time
   - ❑ 25% of the time
   - ❑ 50% of the time
   - ❑ 75% of the time
   - ❑ 100% of the time

9. What percentage of the time, during a 24-hour period, do speak English?
   - ❑ 10% of the time
   - ❑ 25% of the time
   - ❑ 50% of the time
   - ❑ 75% of the time
   - ❑ 100% of the time

10. Which language did you learn to ***speak*** first?
    - ❑ English
    - ❑ Spanish

11. Do you think you speak Spanish with an accent? Yes ____ No ____
12. Do you think you speak English with an accent? Yes____ No____
13. Did you speak any languages other than English while growing up? Yes___ No___
    If so, please list languages here: ____
14. Did your parents speak any languages other than English to you while you were growing up? Yes ___ No ____ If so, please list here: _____________________
15. Where were you born (City & Country)? ___________________________________
16. How many years have you resided in the United States?______________________
17. In which area of the United States have you resided? ________________________
18. Were your parents born in the United States? Yes ____ No ____
19. If not, what is their place of birth?
    Mother____
    Father____
20. How many years have your parents resided in the United States?
    Mother_________________________
    Father__________________________

Hearing History

21. Do you have any medical conditions? If so, please list:

____

____

22. Have you ever had surgery? Yes ____ No ____
    If so, please explain:

____

____

23. Are you currently taking any medications? If so, please list:

____

____

24. Have you ever been diagnosed with a hearing loss? Yes____ No____
    If so, please explain:

____

____

25. Did you have recurrent ear infections as a child? Yes____ No____
If so, please explain:

____

____

26. Is there any other information about yourself that you feel is important or relevant to this study? ____

By signing below, I acknowledge and agree that the information provided in this questionnaire is true and complete to the best of my knowledge.

Signature of Participant	**Printed Name of Participant**	**Date**

Appendix B

English Speech Sample Sentences

Harvard Sentences in English	
1. Slide the box into that empty space.	1. The store walls were lined with colored frocks.
2. The plant grew large and green in the window.	2. The peace league met to discuss their plans.
3. The beam dropped down on the workman's head.	3. The rise to fame of a person takes luck.
4. Pink clouds floated with the breeze.	4. Paper is scarce, so write with much care.
5. She danced like a swan, tall and graceful.	5. The quick fox jumped on the sleeping cat.
6. The tube was blown and the tire flat and useless.	6. The nozzle of the fire hose was bright brass.
7. It is late morning on the old wall clock.	7. Screw the round cap on as tight as needed.
8. Let's all join as we sing last chorus.	8. Time brings us many changes.
9. The last switch cannot be turned off.	9. The purple tie was ten years old.
10. The fight will end in just six minutes.	10. Men think and plan and sometimes act.

***source:* IEEE. 1969. IEEE recommended practice for speech quality measurements, *IEEE Transactions on Audio and Electroacoustics*. Volume AU-17, 225-246.**

Appendix C

Spanish Speech Sample Sentences

Paired Comparison Sentences in Spanish
1. El hombre as un animal bípedo y sin plumas.
2. Después de nosotros vendrán otros más sabios.
3. La honradez en los políticos brilla por su ausencia.
4. Eso es mas que un crimen, es una equivocación.
5. Aquí yace Juan, que fue nada más un pobre hombre.
6. Busca a tu mujer como si buscaras un diamante.
7. ¡Que se paren los muertos que prefieren no estarlo!
8. Dime lo que comes hoy y te diré quien serás mañana.
9. Amé la justicia y por eso muero en el destierro.
10. La ley es a menudo un error común insospechado.
11. No habló muy bien, pero si lo hizo largo tiempo.
12. El que se acuesta con niños, en la cárcel despierta.
13. En cada rebano siempre hay una oveja rebelde.
14. Las águilas no matan moscas aunque si las odian.
15. El que paga no es siempre el que mejor come.
16. ¡Cómo se pasa la vida, como se viene la muerte!
17. Yo solo te cuento lo que otros me han contado.
18. ¡Quién pudiera alejarse de este constante ruido!
19. ¡Mas vale pájaro en mano, que ciento volando!
20. Cada uno debe aprender a soportar su destino.
21. Tú eres el guía, tú el señor y tú el maestro.
22. Tan alta vida espero que muero por que no muero.
23. Yo me comeré uno a uno los granos de esta Granada.
24. Alguien dijo: "El arte es largo y la vida breve."
25. Siempre se necesita un asno para rascar a otro.

source: Auditec®

Appendix D

English Translation of Spanish Sample Sentences

Paired Comparison Sentences – English Translation
1. Men are biped animal without feathers.
2. After us others will come that are more knowledgeable.
3. Honorability in politicians shines because of its absence.
4. That is more than a crime, it is a mistake.
5. Here lays Juan, who was nothing more than a poor man.
6. Look for your wife like if you were looking for a diamond.
7. Separate the dead that prefer not to be dead.
8. Tell me what you eat today and I will tell you what you will be tomorrow.
9. I loved justice and for that I died in exile.
10. The law it is often an unuspected common error.
11. He did not speak very well but he did speak for a long time..
12. He who lies with children in jail awakens.
13. In each herd there is always a black sheep.
14. Eagles do not kill flies but they do hate them.
15. The one who pays it is not always the one who eats best.
16. How life passes by; how death comes.
17. I only tell you what others have told me.
18. Who could get away from this constant noise!
19. It is better to have one bird in the hand than hundreds flying.
20. Each one of us should learn how to deal with our own destiny.
21. You are the guide, you the sire, and you the teacher.
22. Such a good life I await that I die because I don't die.
23. I will eat one by one the grains from this harvest.
24. Someone said "Art is long and life is brief."
25. You will always need a donkey to scratch another.

Appendix E

ACCENT ASSESSMENT FORM

Track Number ____

Date of assessment ______________________________________

Speech Language Pathologist____

ASHA Number _______________________Setting _______________________________

Based on listening to the recorded sample, what level of accent is detectable?

Please circle one

Native (no accent)						**Heavy Accent**
1	2	3	4	5	6	7

____ ____________________

Signature of SLP Date

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