Clinical note

Speech perception in noise for bilingual listeners with normal hearing

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Abstract

Objective: The purpose of this study was to determine if speech-in-noise ability, as measured by SNR-50 and SNR loss in bilingual Spanish listeners with normal hearing, was affected by test difficulty. Design: Quasi-experimental, non-randomized intervention study. Study sample: Two groups of adult listeners participated: monolingual English listeners with normal hearing (N = 12) and bilingual Spanish listeners with normal hearing who were proficient in English (N = 10). The quick speech-in-noise (QuickSIN), the Bamford-Kowal-Bench speech-in-noise (BKB-SIN), and the words-in-noise (WIN) tests were used to assess signal-to-noise ratio (SNR) loss and SNR-50 for both groups. Results: Despite the fact that the bilinguals had normal hearing and were proficient in English, each of the speech-in-noise tests evaluated indicated the Spanish listeners had measurable SNR loss and higher than normal SNR-50s. Performance on the BKB-SIN was best for both groups, indicating test difficulty had a significant impact on speech perception in noise. Conclusions: Bilingual Spanish listeners with normal hearing exhibited a mild SNR loss comparable to that observed for a person with hearing loss. This decreased performance in noise requires an improved SNR for this population to reach a comparable level of comprehension to their monolingual English counterparts.

Key Words: Speech perception in noise, signal-to-noise ratio, signal-to-noise ratio loss, SNR-50, bilingual, monolingual

Communicating in the presence of background noise presents a challenging listening situation for individuals with normal hearing as well as those with hearing loss. When speech signals are presented in background noise, individuals with normal hearing are often able to take advantage of temporary improvements in the signal-to-noise ratio (SNR). This occurs because the signals fluctuate, allowing the listener to hear the message during times when the speech level is higher than the noise. Unfortunately, individuals with hearing loss are not always able to take advantage of these improvements in SNR (Adams et al, 2012).

Further, background noise, whether it is made up of speech or non-speech sounds, degrades the signal and interferes with important bottom-up processing cues needed for accurate speech perception. A bottom-up approach to speech understanding requires the listener to use analytic phonetic and phonemic information from the speech signal and piece it together to form a perception. When bottom-up cues are degraded such that the phonemes are not recognizable due to noise or distortion, listeners typically employ top-down processing to take advantage of other information in the message. A top-down approach involves a more synthetic method of deconstructing the message. Listeners must use context and knowledge of the language to fill in any missing information. The presence of background noise also increases cognitive load and, in particular, working memory. Working memory is thought to be crucial in auditory and language processing because listeners must keep certain aspects of the signal active until they are able to understand the message (Cervera et al, 2009). Studies have also shown that the presence of noise reduces working memory capacity making speech understanding even more challenging (Rudner et al, 2012). When one adds hearing loss to the mix, bottom-up cues are further reduced, diminishing the listener’s ability to use top-down processing due to the increase in cognitive load (Pichora-Fuller et al, 1995; Lunner, 2003; Schneider et al, 2005).

Pure-tone thresholds have long been used by audiologists as the gold standard for measuring hearing. They are important in determining hearing sensitivity at specific frequencies, but they are often inadequate when it comes to predicting speech...
understanding, especially in noise. Pure-tone thresholds primarily reflect the mechanical amplification of quiet sounds provided by the outer hair cells (Moore, 2007); thus the audiogram is primarily a reflection of pure hearing sensitivity (Killion & Niquette, 2000). In contrast, it is the inner hair cells that are responsible for sending most of the auditory signals to the brain, and if there is inner hair cell damage, individuals typically suffer more from a loss of clarity than a loss of sensitivity (Moore, 2007). Kujawa and Liberman (2009) suggest it is the loss of primary auditory nerve fibers that affect how the speech signal is encoded in the auditory nerve, further contributing to this loss of clarity. Unfortunately, this loss of clarity is not reflected in the audiogram. Audiologists consistently evaluate their patients' hearing sensitivity and speech perception in quiet, but many do not assess speech perception in noise as part of their routine battery. Killion (2002) and others (e.g. Dirks et al, 1982; Taylor, 2003) suggest it is important for audiologists to assess speech perception in noise in addition to measuring hearing sensitivity in order to better determine a listener's loss of clarity.

Speech-in-noise ability can be quantified in several ways. Traditionally, an adaptive measure, known as the speech reception threshold (SRT), has been used to represent the SNR at which the listener recognizes 50% of the test items correctly (Levitt, 1978; Plomp & Mimpen, 1979). Today, the SRT is typically referred to as SNR-50. In addition, speech-in-noise ability can be quantified by measuring SNR loss, which refers to the increase in SNR required by a listener to obtain 50% correct perception of words, words in sentences, and sentences compared to normal performance (Etymotic Research, 2001). Thus, SNR loss provides a quantifiable way to document an individual’s difficulty communicating in background noise compared to a listener with normal hearing. Measuring SNR loss also allows clinicians to determine the counseling needs of their patients and to recommend appropriate amplification and discuss realistic expectations.

Because SNR-50 and SNR loss cannot be predicted from standard pure-tone audiometry, multiple evaluation tools are available to measure them. Some of the most common tests include the Quick speech-in-noise test (QuickSIN; Etymotic Research, 2001; Killion et al, 2004); the Bamford-Kowal-Bench speech-in-noise test (BKB-SIN; Bench et al, 1979; Etymotic Research, 2005); and the Words-in-noise test (WIN; Wilson, 2003; Wilson & Burks, 2005). Each of these tests provides a fairly rapid and easy evaluation of a person’s ability to correctly repeat words (WIN) or key words in recorded sentences (QuickSIN and BKB-SIN) by presenting its stimuli at progressively more difficult SNRs. As a result, the stimuli at the end of the list are more difficult to understand than those at the beginning.

Understanding speech in noise can also be challenging for bilingual listeners. According to the U.S. Census Bureau, 19.7% of the population spoke a language other than English at home (Shin & Kominsky, 2010). For 62.3% of those individuals, Spanish or Spanish Creole was the language spoken. In 2014, the Hispanic population of the United States reached 60 million, and this number is estimated to reach 106 million by 2050 (Krogstad, 2014). This growing population diversity will give rise to language diversity as well. Thus, it is important to understand the unique challenges faced by this population in understanding speech in noise.

Several studies have investigated speech recognition abilities in quiet and noise in bilingual listeners (von Hapsburg et al, 2004; Lecumberri & Cooke, 2006; Rogers et al, 2006; Cooke et al, 2008; Weiss & Dempsey, 2008). Overall, this research suggests that bilingual listeners with normal hearing perform more poorly in their second language when the signal is degraded or presented in noise, yet they typically perform as well as native English listeners under quiet conditions. Crandell and Smaldino (1996) investigated the speech perception of children with normal hearing at a variety of SNRs. Children whose second language was English, obtained poorer speech perception scores compared to native English speaking children for the majority of the SNRs. As the SNR worsened, the performance difference between the two groups increased, and the non-native children’s performance was comparable to listeners with moderate sensorineural hearing loss in degraded listening environments. Mayo et al (1997) found adult monolinguals performed better in noise than bilinguals, and learning a second language at an early age helped improve their subjects’ top-down processing in noise.

Weiss and Dempsey (2008) studied bilingual listeners who acquired their second language early and late in life. These native Spanish listeners had superior performance on the hearing in noise test (HINT, Nilsson et al, 1994) presented in their native language compared to the English HINT in both quiet and noise. Those who learned English at an earlier age performed better than those who learned English later in life. Van Engen (2010) also found native English listeners significantly outperformed non-native Mandarin listeners on the HINT but found no significant correlations between age of acquisition, years of studying English, or TOEFL scores on the HINT for this population. Rogers et al (2006) looked at the effects of bilingualism, noise, and reverberation on speech perception in normal-hearing listeners and found significantly poorer performance in all degraded conditions for the bilingual listeners compared to those who only spoke English. Finally, von Hapsburg et al (2004) examined speech-in-noise capabilities among bilingual listeners while varying the speech-in-noise configuration (e.g. speech and noise presented together or separated by 90 degrees). The bilingual listeners had poorer speech-in-noise ability than the monolingual listeners regardless of the configuration. However, when the speech and noise were separated by 90 degrees, both groups of listeners improved their performance in noise. The results of these studies have significant educational and clinical implications for bilingual listeners when communicating in noise.

Research conducted by Magiste (1985) concluded that bilingual listeners have longer processing times in both their first and second languages. Further, Nelson et al (2005) noted that non-native English listeners may rely more on the acoustic signal of speech rather than their linguistic experience, which adds to the degree of difficulty when listening to speech in noise. This research suggests that noisy environments may negatively affect the non-native English speaking population’s performance. Further, some authors have suggested that language proficiency could be a major factor in these listeners’ poor performance in background noise (Shi, 2011).

In an unpublished pilot study in our laboratory, we measured speech-in-noise ability in monolingual and bilingual listeners with normal hearing to determine if there was any measurable SNR loss.
in either group using the QuickSIN (Greene & Mendel, 2009). The bilingual listeners in that study spoke a variety of languages including Spanish and several Asian languages. Our findings revealed the bilinguals performed significantly worse in noise when compared to the monolinguals. In fact, the bilinguals, despite having normal hearing, had speech-in-noise capabilities comparable to a mild SNR loss. Bidelman and Dexter (2015) also examined speech-in-noise performance among monolingual and bilingual normal-hearing listeners and found a significant SNR loss for their bilingual subjects using the QuickSIN.

As the number of bilingual listeners in the United States increases, audiologists must recognize the effects second-language use has on speech perception abilities. If bilingualism generates poorer performance on speech-in-noise tasks as the literature suggests, it is important that we quantify this effect. Normative data for tests used to measure SNR-50 and SNR loss, such as the QuickSIN, BKB-SIN, and WIN have been collected using monolingual English listeners. It is unclear if these same norms are applicable for bilingual listeners, especially if they show a disproportional increase in SNR loss. If audiologists intend to use these tests with their monolingual English speaking patients, they must understand how to accurately interpret the results and modify their speech perception assessment procedures accordingly.

The present study extends the pilot work of Greene and Mendel (2009). The motivation for this study was to determine whether the magnitude of the observed SNR loss found among their diverse group of bilingual listeners was due to the difficulty of the QuickSIN, or if the observed SNR loss truly was an effect of second-language use. The purpose of the present study was to measure SNR-50 and SNR loss using speech-in-noise tests of varying difficulty with bilingual Spanish listeners and monolingual English listeners with normal hearing.

Method

Participants

Two groups of adults participated in this study. Group 1 served as the control group and consisted of monolingual English listeners. Twelve adults (four males, eight females) ranging in age from 23 to 53 years (M = 28) comprised Group 1. Group 2, the experimental group, consisted of 10 adults (three males, seven females) who ranged in age from 18 to 57 years (M = 35). Participants in Group 2 were bilingual listeners whose primary language was Spanish and their secondary language was English. Participants in both groups had no known physical, mental, cognitive, or emotional limitations. All participants passed a pure-tone hearing screening at 20 dB HL bilaterally for the octave frequencies from 250 to 6000 Hz and had normal middle-ear function as evidenced by Jerger type A tympanograms in both ears.

Participants in Group 2 completed an adapted version of the Screening Questionnaire for Prospective Study Participants (Weiss & Dempsey, 2008) regarding acquisition and daily usage of Spanish and English. In addition, English proficiency was assessed through completion of an adapted version of an English proficiency self-evaluation by Transparent Language (2013). Participants were required to score 80% or better on the English proficiency questionnaire to qualify for the study. Among the participants in Group 2, the mean length of English usage was 21.7 years.

Stimuli

Three speech-in-noise tests (QuickSIN, BKB-SIN, and WIN) were administered to all participants in both groups. The QuickSIN consists of 12 lists of six sentences with five key words per sentence. The QuickSIN uses the IEEE sentences (Institute of Electrical and Electronics Engineers (IEEE), 1969) presented in the presence of four-talker babble noise at pre-recorded SNRs which decrease in 5-dB steps from +25 to 0 dB. The IEEE sentences are comprised of words that are not highly predictable from the surrounding context. As a result, the words in the sentences have a difficult vocabulary level and low lexical frequency. Sentences were recorded by a female talker with a General American dialect. Standardization data on the QuickSIN show that averaging the results from several lists improves the reliability of the score (i.e. it increases the number of test items). Thus, four randomly selected lists of the QuickSIN were administered to each participant (Etymotic Research, 2001).

The BKB-SIN contains 192 sentences divided into 18 list pairs spoken by a male talker presented in four-talker babble. The first eight list pairs, which are recommended for use with individuals with normal hearing, were used in this study. These Americanized BKB sentences (Bench et al, 1979) are designed for a first-grade reading level and are short, highly redundant, and simple, both semantically and syntactically. The BKB-SIN was developed primarily for use with both children and cochlear implant recipients. Each list in the pair contains 10 sentences that are four to six words in length. With the exception of the first sentence, which contains four key words, each sentence contains three key words. Sentences are administered at different signal-to-babble (S/B) ratios ranging from -21 to -6 dB in 3-dB increments. The carrier word ‘ready’ is presented at the beginning of each sentence. In this study, three list pairs were presented in random order to each participant.

The WIN contains two lists of 35 monosyllabic words from the NU No. 6 (Tillman & Carhart, 1966) presented in multi-talker babble in an open-set format without linguistic context. Multi-talker babble is presented at a fixed level as the SNR decreases in 4-dB steps from +24 to 0 dB. Five words are presented at each SNR. The list is stopped early if all five words at a single SNR are repeated incorrectly. Each list of the WIN contains four randomizations. One randomization of List 1 and one randomization of List 2 from each of the four randomizations available were administered to each study participant.

Procedure

All testing was conducted in a double-walled sound-treated booth meeting ANSI Standard S3.1-1999 (ANSI, R2013) for maximum permissible ambient noise levels for audiometric test rooms. Hearing screenings were performed using a GSI 61 audiometer and supra-aural TDH-50 headphones, and middle-ear function was assessed using a Maico MI 34 tympanometer.

All recorded speech perception stimuli (QuickSIN, BKB-SIN, and WIN) were routed from a SONY (Model RCD-W500C) compact disc player through the GSI 61 audiometer to supra-aural TDH-50 headphones binaurally. The presentation levels used were those recommended by each test. Thus, the QuickSIN and BKB-SIN stimuli were presented at 70 dB HL and the WIN was presented at 80 dB HL. Participants were instructed to repeat the stimuli heard for all three tests, and all verbal responses were digitally recorded for reliability purposes using a Marantz Professional HD/CD Digital.


Table 1. Speech-in-noise tests and presentation conditions.

<table>
<thead>
<tr>
<th></th>
<th>QuickSIN</th>
<th>BKB-SIN</th>
<th>WIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lists presented</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Stimuli</td>
<td>Sentences</td>
<td>Sentences</td>
<td>Mono syllabic words</td>
</tr>
<tr>
<td>Presentation level*</td>
<td>70 dB HL</td>
<td>70 dB HL</td>
<td>80 dB HL</td>
</tr>
<tr>
<td>Background</td>
<td>Four-talker babble</td>
<td>Four-talker babble</td>
<td>Six-talker babble</td>
</tr>
<tr>
<td>SNR range</td>
<td>+25 to 0 dB</td>
<td>+21 to -6 dB</td>
<td>+24 to 0 dB</td>
</tr>
<tr>
<td>SNR step size</td>
<td>5 dB</td>
<td>3 dB</td>
<td>4 dB</td>
</tr>
</tbody>
</table>

*For the QuickSIN and the BKB-SIN, the level of the sentences was fixed at 70 dB HL, with the level of the multi-talker babble varying for the different SNRs. For the WIN, the multi-talker babble was fixed at 80 dB HL, and the level of the speech varied for the different SNRs.

Administration of the three speech perception tests was counterbalanced so that each participant received the tests in randomized order using a research randomizer. Four of 12 QuickSIN lists, three of eight BKB-SIN list pairs, and the two WIN lists were presented in random order for each participant in Group 1. Corresponding participants in Group 2 were tested using the same list pairs and presentation order as in Group 1. No lists were repeated for any participant throughout the duration of the study to minimize learning and practice effects.

Scoring
For each list administration, the SNR at which 50% of the stimuli were repeated correctly (SNR-50) was calculated. To do this, the total number of key words repeated correctly was determined, SNR-50 was calculated based on the specific instructions for each test, and then the calculated SNR-50 values per list were averaged across the number of lists presented for that test (e.g. four for QuickSIN, three for BKB-SIN, and two for WIN). This resulted in an average SNR-50 per subject per test. For the QuickSIN, SNR-50 was calculated using the formula 27.5 minus the total number of words repeated correctly (Etymotic, 2001); and for the BKB-SIN, SNR-50 was calculated using the formula 23.5 minus the total number of words repeated correctly (Etymotic, 2005). For the WIN, SNR-50 was calculated using the Spearman-Kärber equation reflected in the tables on the score sheet (Wilson, 2011). For the WIN, SNR-50 can be assigned a rating ranging from normal to profound.

SNR loss was also calculated for the QuickSIN and BKB-SIN data. As indicated earlier, SNR loss is defined as the increase in SNR required by a listener to obtain 50% correct words, sentences, or words in sentences, compared to normal performance. For the QuickSIN, SNR loss was determined by subtracting the total number of key words correctly repeated from 25.5 (Etymotic Research, 2001). For the BKB-SIN, SNR loss for each list pair was calculated by first finding SNR-50 for each list and then averaging the lists to find the SNR-50 for the list pair. SNR loss was then calculated by subtracting the average SNR-50 for the subject’s age (−2.5 dB for all adults with normal hearing) from the calculated SNR-50 (Etymotic Research, 2005).

Data analysis
The average SNR-50 and SNR loss measured from each test (QuickSIN, BKB-SIN, and WIN) were subjected to a two-way repeated measures analysis of variance (ANOVA) to determine if there were significant differences between the groups and among the tests. To ensure accuracy in scoring, the recorded talk-back responses from the participants were rescoring by the experimenter offline. Intra-judge scoring reliability was conducted on 30% of the data, using the following formula: [(agreements/(agreements + disagreements))] × 100%. Intra-judge scoring reliability was 97.26%.

Results

English proficiency for bilingual Spanish listeners
The bilingual Spanish listeners scored an average of 93% (SD = 7.2) on the English proficiency questionnaire. Information obtained from the screening questionnaire for prospective study participants indicated that all subjects’ first language was Spanish and 8 of 10 reported they spoke both English and Spanish fluently. Of the remaining two participants, one felt more fluent in English and the other in Spanish. The range of years English was used among the participants was 6 to 52 years (M = 23; SD = 14). Five of the participants learned English prior to the age of five, three learned English between the ages of nine and 14, and the remaining two learned English at the age of 24 and 40, respectively. All participants felt comfortable speaking either language except for two – one of whom was more comfortable speaking English and the other more comfortable with Spanish. On average, the participants in Group 2 spoke English 75% of the time and Spanish 25% of the time. When asked to rate their level of competence speaking, understanding, reading, and writing adult material in each language, the average response was a 4.5 on a scale from 1 to 5 with 1 being ‘poor’ and 5 being ‘excellent.’

SNR-50
Figure 1 shows the monolinguals’ mean SNR-50 scores were −1.86 dB for the BKB-SIN, 2.08 dB for the QuickSIN, and 3.43 dB for the WIN. For the bilinguals, the mean SNR-50 scores were 0.87 dB for the BKB-SIN, 7.60 dB for the QuickSIN, and 6.00 dB for the WIN. A two-way repeated measures ANOVA revealed a statistically significant main effect for group (F(1,40) = 31.562, p < 0.001) and test (F(1,40) = 152.455, p < 0.001), and a significant interaction between group and test (F(1,40) = 11.296, p < 0.001). Power for the performed tests was 1.00. Post-hoc Tukey all pairwise comparisons revealed that the monolinguals exhibited better SNR-50 scores than the bilinguals on all tests. In addition, mean scores on the BKB-SIN for both groups combined were significantly better than those on the QuickSIN (p < 0.001) and the WIN (p < 0.001); scores on the QuickSIN and WIN, however, were not significantly different from each other when the group scores were combined. The significant interaction
revealed that within each group, mean scores on all tests were also significantly different from each other. For the monolingual group, mean scores for the BKB-SIN were the best, then the QuickSIN, and the worst scores were for the WIN. In contrast, for the bilingual group, mean scores on the BKB-SIN were the best, then the WIN, and the worst scores were for the QuickSIN.

**SNR loss**
SNR loss was also calculated for the QuickSIN and BKB-SIN tests; the WIN does not test for SNR loss. The SNR loss results are displayed in Figure 2. For the monolinguals, mean SNR loss was 0.64 dB for the BKB-SIN and 0.08 dB for the QuickSIN. For the bilinguals, the mean SNR loss was 3.37 dB for the BKB-SIN and 5.60 dB for the QuickSIN. A two-way repeated measures ANOVA revealed a statistically significant main effect for group ($F(1,20) = 29.099, p < 0.001$) and test ($F(1,20) = 5.036, p = 0.036$), and a significant interaction between group and test ($F(1,20) = 13.917, p < 0.001$). Post-hoc Tukey all pairwise comparisons revealed the bilinguals exhibited poorer SNR loss scores than the monolinguals on both tests. Mean SNR loss for both groups combined was significantly different between the BKB-SIN and the QuickSIN tests. Post-hoc comparisons, however, showed for the monolinguals there was no significant difference in SNR loss between the two tests. For the bilinguals, on the other hand, SNR loss was significantly lower (better) for the BKB-SIN than for the QuickSIN ($p = 0.001$).

**Discussion**

*Monolingual English listeners compared to bilingual Spanish listeners*

The specific language profile determined for each individual in Group 2 included their age of acquisition, length of English immersion, self-rated English and Spanish proficiency, and language dominance (Shi & Sanchez, 2010). As expected, our
group was quite diverse with regard to language profile and range of years of English usage, yet it is important to note that not all of these variables have the same weight on speech recognition (Shi & Sanchez, 2010). The five participants who acquired English prior to age five, self-reported they either learned English when formal schooling began, or learned it more informally from the people around them. Based on this information, it is suspected that most of the listeners in the group were sequential bilinguals, meaning their acquisition of English occurred mostly after they had acquired Spanish. In addition, many of them had a noticeable foreign accent unlike those reported in Rogers et al (2006). Table 2 displays the language profile data for participants in Group 2 along with their individual performance on the three tests.

Overall, SNR-50 and SNR loss results were significantly poorer for the bilinguals compared to the monolinguals, regardless of the test used. Despite the fact that the bilinguals had normal hearing and were proficient in English, each of the speech-in-noise tests evaluated here indicated the Spanish listeners had measurable SNR loss and higher than normal SNR-50s. In addition, the SNR-50 scores obtained for the monolinguals were more in agreement with typical adult scores reported for each of the three tests when compared to the scores from the bilinguals. For example, the mean QuickSIN SNR-50 for monolinguals (2.08 dB) was well within the range reported by Killion et al (2004) of 2.0 to 2.5 dB compared to the bilinguals (7.60 dB), and the WIN SNR-50 (3.43 dB) was similar to that reported by Wilson et al (2007) of 4 to 5 dB compared to the bilinguals (6.00 dB). For the BKB-SIN, the mean SNR-50 for the monolinguals (−1.86 dB) was similar to the mean reported by Etymotic (2005) of −2.5, while the bilinguals performed more poorly (0.87 dB). Thus, the monolinguals’ mean SNR-50 scores were well within, or better than, the normative range for each test, while the bilinguals’ SNR-50 scores were beyond that range.

These results agree with our previous pilot work and show that the bilingual listeners with normal hearing in the present study performed more poorly in noise when compared to their monolingual English speaking counterparts. Specifically, the bilinguals in this study had an SNR loss ranging from 3.37 on the BKB-SIN to 5.60 on the QuickSIN. This suggests that these Spanish listeners need the signal 5.37 to 7.60 dB more intense than the noise in order to obtain 50% correct perception of sentences. When compared to a 2-dB SNR loss for individuals with normal hearing, the Spanish listeners in this study can be classified as having a mild SNR loss (Killion et al, 2004). Because the proposed SNR level is only adequate to score 50% correct, it is likely that the signal may need to be elevated even higher for these listeners to get full comprehension of speech.

According to Langdon’s (2008) bottom-up processing theory, phonetic aspects of words are used to decode a message. When a noisy environment makes the phonetic aspects more difficult to perceive, even the monolingual English listener experiences some difficulty. Because bilingual Spanish listeners do not have the same English phonetic inventory as monolingual English listeners, the results obtained in this study clearly suggest it is more difficult for bilinguals to understand speech in noise. Yet, if these subjects’ hearing evaluation consisted only of an audiogram and traditional word recognition in quiet, the audiologist would have missed this important piece of the diagnostic puzzle. The results from the present study suggest measuring SNR loss (and SNR-50), as suggested by Killion and others, provides important diagnostic and potential rehabilitative information not available from a simple audiogram. As seen here, even when the bilinguals’ pure-tone thresholds are within normal limits, their speech understanding in noise is not.

**Effect of test difficulty**

We used several speech-in-noise tests to determine if the observed SNR loss for these bilingual Spanish listeners was due to test difficulty or whether it was truly an effect of second-language use. When looking at each test’s SNR-50 with groups combined, we found significant differences in performance among the tests, with the BKB-SIN exhibiting the best scores. As indicated above, scores on the QuickSIN and WIN were not significantly different from each other except when test performance was analysed within each group. The higher WIN scores could possibly be due to the higher presentation level used for that test compared to the other tests. The fact that no significant difference was found between the QuickSIN and WIN for the bilinguals is probably why we found no significant effect when the groups were combined. It appears that the stimuli of the QuickSIN and WIN are more difficult for these Spanish listeners

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*Table 2. Language profile data and speech perception scores for listeners in group 2.*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (in years)</th>
<th>Language spoken fluently</th>
<th>Reported language dominance</th>
<th>Primary language spoken at home</th>
<th>QuickSIN SNR-50 (in dB)</th>
<th>BKB-SIN SNR-50 (in dB)</th>
<th>WIN SNR-50 (in dB)</th>
<th>QuickSIN SNR loss (in dB)</th>
<th>BKB-SIN SNR loss (in dB)</th>
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<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>E and S</td>
<td>None</td>
<td>E</td>
<td>7.50</td>
<td>1.17</td>
<td>7.20</td>
<td>5.50</td>
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<tr>
<td>2</td>
<td>40</td>
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<td>E</td>
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<tr>
<td>3</td>
<td>5</td>
<td>E and S</td>
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<td>S</td>
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<td>4</td>
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<td>E and S</td>
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<td>S</td>
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<td>5.60</td>
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<tr>
<td>5</td>
<td>5</td>
<td>E and S</td>
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<td>E</td>
<td>7.50</td>
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<tr>
<td>6</td>
<td>24</td>
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<td>0.83</td>
<td>5.60</td>
<td>8.00</td>
<td>3.33</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>E</td>
<td>None</td>
<td>S</td>
<td>3.75</td>
<td>−0.50</td>
<td>5.20</td>
<td>1.75</td>
<td>2.00</td>
</tr>
</tbody>
</table>

*All participants in this group learned Spanish as their first language. Language dominance was reported as the language the participants were most comfortable speaking. The language profile data were self-reported by each participant. E = English; S = Spanish.*
given that their performance on these two tests was fairly similar and considerably poorer when compared to the BKB-SIN. The isolated monosyllabic words used in the WIN forced the listeners to rely on acoustic cues of the target item rather than linguistic context. In contrast, because the IEEE sentences in the QuickSIN have proper syntax but lack strong semantic cues, the contextual cues available in the QuickSIN were greater. Therefore, the listeners’ reliance on acoustic cues decreased. Thus, the WIN accentuates the listeners’ ability to take advantage of bottom-up cues, and the QuickSIN underscores their ability to use top-down processing. Our data suggest that the monolingual English listeners were more successful with both bottom-up and top-down processing than the bilingual Spanish listeners when listening to the QuickSIN and WIN stimuli. Further, these listeners probably performed best on the BKB-SIN because of the simple sentence structure and additional semantic context when compared to the monosyllabic words in the WIN and the IEEE sentences in the QuickSIN. Therefore, better recognition performance is expected on the BKB-SIN than on either the WIN or QuickSIN.

A similar finding was seen when comparing SNR loss for the monolinguals; no significant difference was found for SNR loss between the QuickSIN and BKB-SIN. This finding probably occurred because this group of listeners had little measurable SNR loss (<1 dB) for each test. In contrast, a large SNR loss was measured for the bilinguals for both tests, and significantly greater SNR loss was measured on the QuickSIN compared to the BKB-SIN.

Our findings suggest that the BKB-SIN yielded the best SNR-50 values compared to either the QuickSIN or WIN for both groups of listeners. This finding is in agreement with the results from Wilson et al (2007) who found listeners with normal hearing and hearing loss scored better on the BKB-SIN. Despite the better scores, however, Wilson et al (2007) found the BKB-SIN was least able to provide separation in terms of recognition performance between listener groups. Thus, a more difficult test, such as the QuickSIN or WIN, might prove more useful regarding speech-in-noise performance.

Overall, our results suggest that there is an effect of test difficulty. The sentences in the QuickSIN are longer and contain fewer contextual cues compared to the BKB-SIN sentences. Similarly, single word recognition on the WIN resulted in poorer performance than sentence recognition on the BKB-SIN. The QuickSIN and WIN appear to have a more similar level of difficulty which could account for the smaller SNR-50 differences observed between these two tests for both groups. Another possible contributing factor to the difference in test results could be the differing SNR step sizes used for the three tests. A 5-dB step size was used in the QuickSIN ranging from +25 to 0 dB, a 4-dB step size was used in the WIN (+24 to 0 dB), and a 3-dB step size was used in the BKB-SIN (+21 to -6 dB). Given that performance was best for both groups on the BKB-SIN, it is possible the 3-dB step size could be contributing to the improvement in scores.

Regardless of the test used, bilingual Spanish listeners in this study exhibited poorer SNR-50 and SNR loss results compared to their matched monolingual English-speaking controls despite having normal hearing. Thus, our findings indicate that second language use and test difficulty have a significant impact on speech perception in noise that cannot be determined simply from an audiogram. The clinical implications of these findings suggest measuring SNR-50 and/or SNR loss can provide important additional information about the challenges a bilingual listener may experience in background noise. If audiologists continue to use speech perception tests normed on monolingual English listeners with their Spanish-speaking patients, it is important that such test results be interpreted carefully. Audiologists must consider their patients’ daily communication partners and communication environments to determine what language is most commonly used. If Spanish is used more frequently, for example, the BKB-SIN may be a more appropriate test to use. If English is mostly used, however, the QuickSIN may be more indicative of speech perception difficulties.

One of the challenges of studies that use bilingual listeners is the fact that there are no standardized methods of documenting one’s level of English proficiency (Shi, 2011). The tools used in this study, though used in some other studies, are not standardized and may be limited in their ability to provide a reliable picture of our subjects’ English proficiency.

Future directions

Though this study focused on adults, future research directions should measure speech perception in noise with bilingual children. If bilingual children show similar results to the adults tested here, such findings would have significant clinical implications regarding modifications that may be needed in the classroom to improve their speech understanding in noise. Installation of sound field FM systems for example (Mendel et al, 2003) could enhance the SNR in the classroom and improve the listening environment. In addition, future research should evaluate the speech-in-noise performance of bilingual listeners who have hearing loss. Given the results of the present study, documenting speech perception in noise is likely to have greater impact on the recommendations made for bilingual hearing-impaired listeners who may benefit from amplification that utilizes algorithms designed to enhance listening in noise, such as directional microphone technology. Lastly, the present study further demonstrates the need for development of speech perception test materials in Spanish.

Summary and Conclusion

Bilingual Spanish listeners with normal hearing who are proficient in English performed significantly poorer in noise when compared to their monolingual English speaking controls. Performance on the BKB-SIN was best for both groups indicating test difficulty had a significant impact on speech perception in noise that cannot be determined simply from an audiogram. These bilingual Spanish listeners with normal hearing exhibited a mild SNR loss comparable to that observed for a person with hearing loss. This suggests the possibility of significant auditory processing degradation for the Spanish speaking population studied when listening to English in the presence of background noise. This decreased performance in noise requires an improved SNR for this population to reach a comparable level of comprehension to their monolingual English speaking counterparts. It is recommended that speech-in-noise tests be used with bilingual patients as part of the audiometric test battery to provide additional insight into their speech perception capabilities. Future research efforts should focus on additional ways to better understand bilingual English listeners’ speech understanding in noise including children and those with hearing loss.
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References


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