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Research Article

Age-Related Changes in Speech Recognition Performance in Spanish–English Bilinguals' First and Second Languages

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Purpose: The purposes of the current study were to examine the effect of age on Spanish–English bilinguals' speech recognition performance and to identify differences in speech recognition performance between Spanish and English bilinguals' 1st and 2nd languages.
Method: Fifteen younger adult Spanish–English bilinguals, 15 older adult Spanish–English bilinguals, 15 younger adult English monolinguals, and 15 older adult English monolinguals participated in this study. Bilingual participants had learned Spanish from birth and began learning English by the age of 4 years (*SD* = 2.7). Speech recognition performance was measured using the Spanish and English versions of the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994) presented in quiet and in a speech-shaped background noise. Participants also completed a self-assessment of the listening effort they expended on the HINT in background noise.
Results: There were no significant differences in performance within or between the participant groups for the HINT in quiet. In background noise, Spanish–English bilinguals performed significantly poorer and had increased listening effort on the English HINT than English monolinguals, with the most significant effects evidenced for the older Spanish–English bilingual group. Overall, the bilingual participants performed significantly better and expended less listening effort on the Spanish than on the English HINT in background noise, despite learning both languages at an early age.
Conclusions: Older Spanish–English bilinguals are at an increased disadvantage in understanding English in background noise compared to older English monolinguals. This suggests that current clinical audiological evaluation and treatment procedures may need to be modified to better serve an older bilingual population.

Bilingualism, the practice of speaking two languages on a regular basis, is growing in prevalence in the United States (Grosjean, 2010). Currently, over 20% of people living in the United States are bilingual, the majority of whom speak Spanish and English. Persons of Hispanic/Latino ethnicity represent 18% of the U.S. population and are the fastest growing minority group, and 62% of this group is Spanish–English bilinguals (2016 American Community Survey, U.S. Census Bureau). It has been projected that the United States will be the largest Spanish-speaking country in the world by 2050 (Krogstad & Lopez, 2014). The rapid growth in the U.S. Hispanic population, combined with higher life expectancies for Hispanics, will almost triple the proportion of adults over the age of 65 years in the United States who are Hispanic, from 7% in 2009 to 20% in 2050. Thus, the proportion of older Hispanic bilingual adults living in the United States will increase substantially (2014 National Population Projections, U.S. Census Bureau), making it critical to understand the impact of bilingual experience in older age.

One aspect of bilingual experience in older age, which is not well understood, is speech recognition performance. Although several studies have examined speech recognition performance in bilingual individuals, the focus has primarily been on younger adult bilinguals (e.g., Golestani, Rosen, & Scott, 2009; Rogers, Lister, Febo, Besing, & Abrams, 2006; Shi & Sánchez, 2010) and bilingual children (e.g., Crandell & Smaldino, 1996; Nelson, Kohnert, Sabur, & Shaw, 2005). Based on these studies, there is strong evidence to suggest that bilingual speakers have poorer speech recognition performance compared to monolingual speakers in background noise and reverberation, despite performing

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similarly to their monolingual speaking peers in quiet listening conditions. This has been shown to be true even when testing is performed in the bilingual's dominant language (Rogers et al., 2006), when bilinguals have no noticeable foreign accent (Rogers et al., 2006), and when bilinguals had learned both languages from birth (Mayo, Florentine, & Buus, 1997).

For example, Mayo et al. (1997) examined the performance of native Spanish–English bilingual speakers between the ages of 21 and 37 years who learned English before the age of 6 years (early bilinguals) or after the age of 14 years (late bilinguals) and native English monolingual speakers between the ages of 20 and 29 years on the Speech Perception in Noise Test (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984). The early Spanish–English bilinguals and English monolinguals were able to tolerate a greater amount of background noise when understanding English in noisy listening situations than the late bilinguals. However, although the early bilinguals performed better than the late bilinguals, they did not demonstrate the same level of speech recognition in noise performance compared to the monolinguals. The authors concluded that, although age of acquisition plays a prominent role in nonnative listeners' ability to discriminate second language (L2) speech in the presence of background noise, even bilinguals who learned both of their languages at an early age are still at a disadvantage in understanding speech in background noise in their L2 compared to their monolingual peers. Similarly, von Hapsburg, Champlin, and Shetty (2004) found that Spanish–English bilinguals, who learned English after the age of 10 years, performed similarly to younger adult English monolinguals on the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994) in quiet; however, in background noise, the bilinguals needed, on average, a signal-to-noise ratio that was 3.9 dB higher than their monolingual peers to achieve a 50% correct recognition score on the HINT.

Although many studies have examined differences between English monolingual and Spanish–English bilingual listeners' recognition of English speech, relatively few have examined how bilingual performance compares between English and Spanish tests of speech recognition (Lew & Jerger, 1991; Lopez, Martin, & Thibodeau, 1997; Shi & Sánchez, 2010; Weiss & Dempsey, 2008). Since a bilingual's two languages are thought to interact to form a unique linguistic system (Grosjean, 1989, 1997), and bilinguals are known to combine linguistic cues from both languages, there is reason to predict that a bilingual individual will not achieve the same level of performance in both of their languages, even if they acquired the two languages at a very early age. In fact, it has been suggested that bilinguals will always be more dominant in one of their languages even when they are exposed to both languages at birth (Sebastián-Gallés, Echeverría, & Bosch, 2005). Thus, in order to obtain a more complete understanding of bilinguals' speech recognition abilities, it is advisable to administer speech recognition assessments in the bilinguals' two languages.

Studies that have examined bilinguals' speech recognition performance in English and Spanish suggest that Spanish–English bilinguals perform better in Spanish than in English (e.g., Lew & Jerger, 1991; Lopez et al., 1997; Shi & Sánchez, 2010; Weiss & Dempsey, 2008). Weiss and Dempsey (2008) examined the performance of early Spanish–English bilinguals (i.e., bilinguals who learned English before the age of 7 years) who were between the ages of 18 and 42 years and late Spanish–English bilinguals (i.e., bilinguals who learned English after the age of 11 years) who ranged in age from 19 to 33 years on the English and Spanish versions of the HINT. Both groups of bilingual participants performed better on the Spanish version of the HINT than on the English version of the HINT in quiet and in background noise. The early bilingual group outperformed the late bilingual group on the English version of the HINT in background noise, whereas the late bilinguals outperformed the early bilingual group on the Spanish version of the HINT in quiet and in background noise. The authors concluded that bilingual individuals perform better in their first language (L1) compared to their L2 even when they learned both languages at an early age.

Differences in speech recognition performance between monolingual and bilingual listeners or between native and nonnative languages in the same bilingual listeners may be caused by an increased demand for cognitive processing resources (i.e., increased listening effort) due to factors unique to bilinguals' management of two languages. For instance, bilinguals have more words, overall, in their combined vocabulary than monolinguals, with both languages grouped into one large lexicon (Kroll & De Groot, 1997). Even when the bilingual knows the language of testing, they must still search the aggregate lexicon of both languages to retrieve the word (Grosjean, 1989). Similarly, a bilingual has two phonological inventories and must select a target phoneme from among a larger number of alternatives compared to a monolingual speaker who has only one phonological inventory (Flege, Munro, & MacKay, 1995). In addition, during a conversation, a bilingual speaker must actively select the language they intend to use and deactivate their nonactive language in order to prevent the two languages from interfering with one another (Grosjean, 1997). It has also been suggested that differences in language processing between bilinguals and monolinguals may be due to the fact that bilinguals simply spend less time using words particular to each language relative to monolinguals (Gollan, Montoya, Cera, & Sandoval, 2008; Gollan et al., 2011).

Speech recognition may not be problematic for bilinguals when they are in quiet listening conditions and/or in situations where the signal quality is high and task demands are low, primarily because the greater need for a bilingual's cognitive resources may have no functional effect. However, when speech is degraded by background noise or reverberation, the bilingual's need for greater cognitive resources (increased listening effort) may have a significant impact on their speech recognition performance. Also, the listening effort expended on speech recognition in noise tasks may differ between a bilingual's two languages. This is because processing speech in an L2 is inherently less automatic and may draw more cognitive resources, increasing effortful listening, than processing speech in an L1 (Lecumberri, Cooke, & Cutler, 2010).

Age-related changes in audition and cognition may further deplete an individual's cognitive reserves, compounding the negative effects of bilingualism on speech recognition compared to monolinguals. Numerous studies have shown that older monolingual adults perform similarly to younger monolingual adults in relatively undemanding listening conditions (i.e., quiet) but have more difficulty and increased listening effort understanding speech in noisy listening conditions than their younger counterparts do (Dubno & Ahlstrom, 1997). This is thought to be the result of decreased cognitive capacity and an increase in reliance on effortful cognitive processes with age (Desjardins & Doherty, 2013; Gosselin & Gagné, 2011; Peelle, 2018). Thus, older bilinguals may be at a greater disadvantage in understanding speech in background noise than older monolinguals. Whereas all older adults may experience age-related changes in audition and cognition that can deplete cognitive reserves for processing speech, older bilinguals, unlike their monolingual peers, may also face additional processing demands from managing two language systems.

To this author's knowledge, no studies have directly examined speech recognition performance in older Spanish–English bilinguals' L1 and L2. Thus, the purposes of the current study were to determine how Spanish–English bilinguals' speech recognition performance changes with age and to identify differences in speech recognition performance for bilinguals' L1 and L2. To this end, we measured the effect of age and language experience on listeners' speech recognition performance and self-rated listening effort for English and Spanish sentences in quiet and in speech-shaped background noise. We hypothesized that older adults would show poorer speech recognition performance scores and increased listening effort for English speech in background noise than younger adults, that bilinguals would show poorer speech recognition performance scores and increased listening effort for English speech in background noise than monolinguals, and that bilinguals would show poorer speech recognition performance scores and increased listening effort in their L2 (English) compared to their L1 (Spanish).

Method and Procedure

Participants

A total of 61 participants divided into four groups, 15 younger English monolinguals (YMs) aged 21–27 years (M = 23, SD = 1.85), 16 younger Spanish–English bilinguals (YBs) aged 20–28 years (M = 24, SD = 2.68), 15 older English monolinguals (OMs) aged 49–67 years (M = 58, SD = 6.36), and 15 older Spanish–English bilinguals (OBs) aged 54–65 years (M = 58, SD = 3.56), participated in this study. Participants were recruited from The University of Texas at El Paso and the surrounding El Paso, Texas, region. The University of Texas at El Paso Institutional Review Board for Human Subjects approved this study, and participants were compensated hourly for their participation.

Participants had pure-tone hearing thresholds < 25 dB HL at octave frequencies from 250 to 4000 Hz, bilaterally (American National Standards Institute, 2007), and less than a 10-dB difference between air- and bone-conduction thresholds at each individual test frequency. All participants reported that they were in good general health and had no history of neurological disease. Additionally, all of the older participants in this study passed the Short Portable Mental Health Status Questionnaire (Pfeiffer, 1975), a 10-question screening that assessed cognitive impairment in older adults.

On average, participants reported that they completed 15.5 years (SD = 2.5) of formal education taught in English. There were no significant differences in years of education taught in English between the four participant groups in this study, $F(3, 60) = 0.78$, $p = .5$. A Hollingshead Two Factor Index (Hollingshead, 1957) of socioeconomic status was obtained for each participant. There were no significant differences between Hollingshead scores, $F(3, 60) = 2.1$, $p = .11$, for the four participant groups. Participants also completed the Digit Span subtest from the Wechsler Adult Intelligence Scale–Third Edition (Wechsler, 1997) to estimate cognitive ability. There were no significant differences, $F(3, 60) = 0.825$, $p = .49$, in Digit Span scores between the four groups (see Table 1 for hearing threshold, digit span, and demographic information for the four participant groups).

A comprehensive linguistic profile was obtained for each participant using a subjective (i.e., Language Experience and Proficiency Questionnaire [LEAP-Q]; Marian, Blumenfeld, & Kaushanskaya, 2007) and an objective (i.e., The Woodcock-Muñoz Language Survey III [WMLS III]; Woodcock, Alvarado, & Ruef, 2017) measure of language proficiency. The LEAP-Q is a self-report questionnaire that assesses a number of linguistic variables related to individuals' language use, language history, and self-rated proficiency in reading, writing, speaking, and understanding. Responses obtained on the LEAP-Q showed that the two English monolingual groups had learned English from birth and had no other language. The bilingual participants reported that, on average, they had been exposed to Spanish at birth (M = 0.9 years, SD = 1) and to English by the age of 4 years (M = 4.1, SD = 2.7). Bilingual participants in this study used English, on average, 50% (SD = 29) of the time in a given day.

Participants also completed the Oral Comprehension subtest from the WMLS III, which is a standardized normed objective language assessment. The Oral Comprehension subtest measures an individual's ability to listen to and comprehend audio-recorded passages in English and in Spanish. Participants had a mean age equivalency score of 18.8 years (SD = 4) on the English Oral Comprehension subtest. There were no statistically significant differences in performance between the four participant groups, $F(3, 60) = 0.2$, $p = .89$, suggesting that all groups had similar English auditory language comprehension skills.

Table 1. Participant demographic information.

Demographics	YM	YB	OM	OB
Age (years)	23.1 (1.9)	24.4 (2.7)	57.7 (6.4)	58.5 (3.6)
Years of education	16.1 (1.4)	16.4 (1.7)	15.6 (2.8)	15.7 (2.5)
Years of education in English	16.1 (1.4)	14.8 (2.9)	15.6 (2.8)	15.6 (2.8)
Digit span forward recall	10.1 (2.0)	10.1 (1.8)	11.3 (2.2)	10.2 (1.6)
Digit span backward recall	6.8 (1.1)	6.9 (1.7)	6.7 (2.7)	5.9 (1.8)
Digit span total	16.9 (2.4)	17.0 (2.9)	17.9 (4.2)	16.1 (2.8)
PTA (dB HL)	1.8 (5)	2.4 (5)	9.7 (7)	6.5 (6)
Hispanic (% of participants)	60	100	7	100
Hollingshead score	24 (11)	26 (12)	29 (16)	27 (16)

Note. Values are mean (standard deviation), unless otherwise indicated. Hollingshead score was obtained to measure social status of the participants (Hollingshead, 1957). Pure-tone average (PTA) is the average of pure-tone thresholds at 500, 1000, and 2000 Hz averaged across the right and left ears. YM = younger English monolinguals; YB = younger Spanish–English bilinguals; OM = older English monolinguals; and OB = older Spanish English bilinguals.

The English monolingual participants had mean age equivalency scores of 3.1 years ($SD = 0.5$) on the Spanish Oral Comprehension subtest, which is consistent with the participants being English monolinguals. Bilingual participants had mean age equivalency scores of 12.4 years ($SD = 4.5$) on the Spanish Oral Comprehension subtest. Thus, both groups of bilingual participants scored significantly better on the WMLS III in English compared to Spanish ($t = 5.4$, $p = .001$). Since language learning is thought to be contextually based (Bernat & Gvozdenko, 2005), it was not surprising that the bilinguals in the current study performed better on a formal academic standardized language assessment in English than in Spanish (even though they learned Spanish first), as they had received most of their formal education in English and would likely have had more experience using English (their L2) on this type of assessment. Table 2 shows performance scores on the WMLS III and selected variables obtained on the LEAP-Q for the four participant groups.

Speech Recognition Task

Speech recognition was measured in quiet and in a speech-shaped background noise using the English (Nilsson et al., 1994) and Spanish (Soli, Vermiglio, Wen, & Filesari, 2002) versions of the HINT. The HINT stimuli consisted of 25 lists of sentences, with each list having 20 sentences rated at a first-grade reading level spoken by adult male native speakers of English and Spanish for the two versions of the test, and a speech-shaped noise (SSN) matched to the long-term speech spectrum of the sentences. The experimental setup used in the current study was consistent with the manufacturer's operating instructions for the HINT for Windows Audiometric System (Hearing Test System, LLC, 2012). Participants were seated in a double-walled audiometric test booth with the loudspeaker located 1 m from the center of the participant's head and 45 in. from the floor. The test stimuli were delivered through the automated protocol provided by the HINT for Windows Audiometric System and were presented through a GSI Audiostar (Grason-Stadler), a two-channel audiometer to the loudspeaker. Both the speech and the noise were always presented through a single loudspeaker located at 0° azimuth relative to the participant's head. The loudspeaker was calibrated in accordance with the HINT test protocol. This calibration procedure ensured the accuracy of the level of the speech stimuli and verified that the SSN was presented at a constant level of 65 dBA. Calibration was checked at regular intervals throughout the investigation. Participants were instructed to listen to each HINT sentence and repeat it back to the examiner. Test instructions were always presented in the language of test administration to ensure a consistent linguistic mode (Grosjean, 2001).

Self-Assessment of Listening Effort

Participants' self-reported estimates of listening effort expended on the speech-in-noise task were measured using a seven-category scaling procedure. Listening effort was rated on a 7-point Likert scale adapted from Krueger, Schulte, Brand, and Holube (2017), which represented the range of extreme effort to no effort (i.e., *extreme effort* [6], *much effort* [5], *considerable effort* [4], *moderate effort* [3], *little effort* [2], *very little effort* [1], and *no effort* [0]). Immediately after the participant completed two lists of the HINT (i.e., 40 sentences), they were instructed to rate how much effort it required for them to perform the entire sentence recognition task in background noise in English. The bilingual participant groups also rated how much effort it required for them to perform the sentence recognition task on the HINT in background noise in Spanish.

Procedure

Testing was performed in one 2-hr test session. All of the preliminary testing in the current study was conducted in English for all participants. Participants' air- and bone-conduction thresholds were obtained at octave frequencies from 250 to 8000 Hz in the right and left ears. Participants completed a demographic information sheet, the LEAP-Q (Marian et al., 2007), the Digit Span Test (Wechsler, 1997),

Table 2. Participants' linguistic profiles.

Linguistic proficiency variables	YM	YB	OM	OB
LEAP-Q				
Age on Spanish acquisition	—	0.8 (1.0)	—	1.0 (1.1)
Age on English acquisition	0.3 (0.6)	4.8 (2.8)	0.9 (1.1)	3.4 (2.7)
L1 % daily use	100.0	45.3	100.0	55.0
L2 % daily use	N/A	54.7	N/A	45.0
L1 understanding proficiency	9.3 (0.9)	8.7 (1.4)	9.4 (0.9)	8.3 (1.4)
L1 speaking proficiency	9.6 (0.7)	8.1 (1.6)	9.5 (0.8)	7.9 (1.4)
L1 reading proficiency	9.3 (0.7)	7.6 (2.0)	9.4 (0.9)	7.7 (2.2)
L2 understanding proficiency	—	8.8 (1.2)	—	7.9 (2.0)
L2 speaking proficiency	—	8.6 (1.5)	—	7.5 (2.2)
L2 reading proficiency	—	8.8 (1.0)	—	7.1 (2.6)
WMLS III English				
Raw scores	30.1 (2.5)	30.3 (3.0)	31.5 (3.4)	30.5 (3.0)
AE	18.7 (4.1)	18.2 (4.2)	19.4 (4.1)	18.9 (4.4)
GE	11.4 (2.6)	11.0 (2.7)	11.6 (2.5)	11.2 (2.8)
WMLS III Spanish				
Raw scores	1.5 (3.8)	27.7 (4.3)	1.5 (2.8)	26.9 (2.2)
AE	3.1 (0.5)	13.4 (5.2)	3.1 (0.4)	11.4 (3.8)
GE	0.0 (0.0)	7.3 (4.0)	0.0 (0.0)	6.3 (3.4)

Note. Values are mean (standard deviation), unless otherwise indicated. The em dashes mean that the linguistic proficiency variable was not applicable to the participant group. YM = younger English monolinguals; YB = younger Spanish–English bilinguals; OM = older English monolinguals; OB = older Spanish–English bilinguals; LEAP-Q = Language Experience and Proficiency Questionnaire; L1 = first language; L2 = second language; N/A = not applicable; WMLS III = Woodcock-Muñoz Language Survey III; AE = age equivalent; GE = grade equivalent.

and the Short Portable Mental Health Status Questionnaire (Pfeiffer, 1975). The Oral Comprehension subtest of the WMLS III in Spanish and in English (Woodcock et al., 2017) was then administered in a counterbalanced order. Last, participants were administered the HINT in quiet and in the SSN. The English monolingual participants were administered the HINT in English only, and the Spanish–English bilingual participants were administered both the English and Spanish versions of the HINT in a counterbalanced order. Prior to experimental trials, monolingual participants completed a practice test session of the HINT in English. Spanish–English bilingual participants completed two practice test sessions of the HINT: one in English prior to administration of the English version of the HINT and one practice test session in Spanish prior to administration of the Spanish version of the HINT. The practice test session always consisted of one list of 20 sentences presented in quiet. Following the practice session, participants were administered two lists of 20 HINT sentences in quiet followed by two lists of 20 HINT sentences presented in the SSN, in accordance with standard test administration procedure for the HINT. The examiner scored the five to six key words in each sentence; a sentence was scored as correct if all key words were repeated correctly. In the quiet test condition, HINT performance was scored as the percentage of correctly repeated sentences. In the background noise condition, the standard HINT-adaptive procedure for administration was used to determine the signal-to-noise ratio required for participants to achieve 70% correct performance on the test. This procedure utilizes 4-dB step sizes for the first four sentences and 2-dB step sizes for the remaining 16 sentences in each 20-sentence test block. The HINT was scored in real time by one of the examiners who was proficient in both English and Spanish. Immediately following the two 20-sentence test blocks of HINT sentences, participants rated on the 7-point scale (i.e., *no effort* to *extreme effort*) how effortful it was for them to perform the sentence recognition task as described in the self-assessment of listening effort section.

Results

HINT Performance in Quiet

English monolinguals' mean performance on the English HINT in quiet and Spanish–English bilinguals' mean performance on the English and Spanish HINT in quiet are shown in Table 3. A one-way analysis of variance (ANOVA) was performed to compare participants' performance in English across the four groups. There were no significant differences in performance between the four participant groups on the English HINT in quiet, $F(3, 60) = 1.35$, $p = .3$. A

Table 3. Participants' mean performance scores (%) on the Hearing in Noise Test (HINT) in quiet.

Participant group	English HINT	Spanish HINT
Young monolinguals	100 (0)	—
Young bilinguals	99.6 (1)	99.4 (0.8)
Older monolinguals	99.8 (0.5)	—
Older bilinguals	99.5 (0.7)	99.6 (0.8)

Note. Values are mean (standard deviation). Em dashes mean monolingual participants completed the LEAP-Q for English (L1), their only language.

paired-samples t test was performed to compare bilingual's performance across English and Spanish versions of the HINT in quiet. There was no significant difference between the bilingual participants' performance on the English HINT and Spanish HINT in quiet ($t = -0.004$, $p = .99$).

English HINT Performance in Background Noise

Figure 1 shows mean performance on the English HINT in background noise for the four participant groups. A between-subjects univariate ANOVA with age (younger and older) and language group (monolingual and bilingual) as the two between-subjects factors showed significant main effects of language group, $F(1, 57) = 14.18$, $p < .001$, and age, $F(1, 57) = 4.00$, $p = .05$. There was no significant interaction between language group and age, $F(1, 57) = 0.27$, $p = .61$. Bilinguals performed significantly poorer on the English HINT in background noise than the monolingual participants, and the older participants, overall, performed significantly poorer on the English HINT in background noise than the younger participants.

Bilinguals' Performance on the English and Spanish Versions of the HINT in Background Noise

The HINT sentences are equated for difficulty within and across languages, allowing for cross-language comparisons between performance conditions (Soli et al., 2002). Figure 2 shows mean performance on the English HINT and the Spanish HINT in background noise for the older and younger bilingual participant groups. A mixed-model ANOVA with test language (English and Spanish) as the within-subject variable and age group (younger and older) as the between-subjects variable showed a main effect of test language, $F(1, 29) = 65.74$, $p < .001$, and a significant main effect of age, $F(1, 29) = 6.5$, $p = .01$. Both groups of bilingual participants performed significantly better on the Spanish HINT than the English HINT in background noise, and the younger bilinguals performed better than the older bilinguals on both the English and Spanish versions of the HINT in background noise. Thus, both groups of bilinguals had speech recognition performance scores in background noise that were significantly better in their L1 (the language they acquired first) compared to their L2. There was no significant interaction between test language and age.

Figure 1. Mean speech recognition performance scores in signal-to-noise ratio on the English Hearing in Noise Test in background noise for the four participant groups. Error bars represent ± 1 *SD* from the mean.

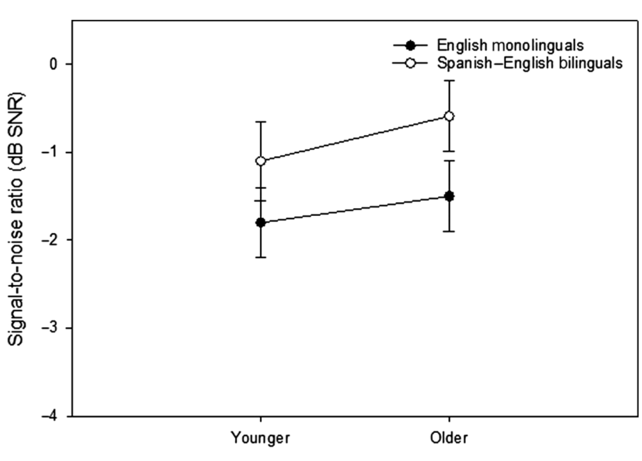
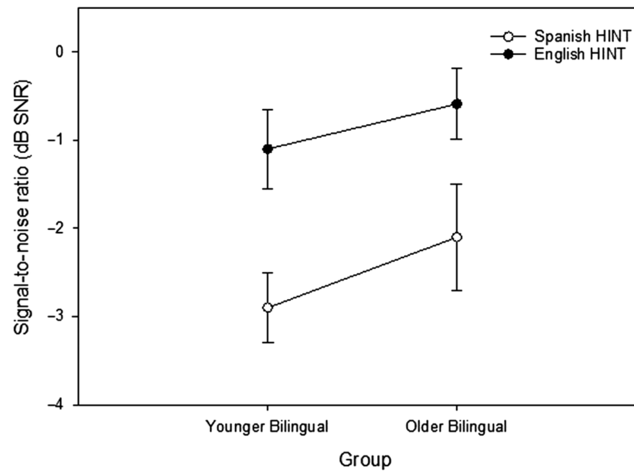


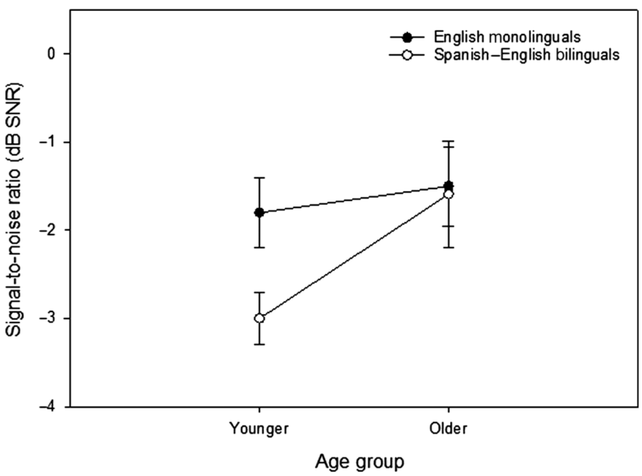
Figure 2. Mean speech recognition performance scores in signal-to-noise ratio on the English and Spanish versions of the Hearing in Noise Test (HINT) in background noise for the four participant groups. Error bars represent ± 1 *SD* from the mean.



Speech Recognition Performance in Participants' L1

To further examine speech recognition in noise performance differences between English monolinguals and Spanish–English bilinguals, we compared participants' speech recognition in noise performance on the HINT in noise in each participant's L1 (i.e., Spanish for the bilinguals, English for the monolinguals). We were specifically interested in determining if the bilingual disadvantage for speech recognition in noise would still be evident when participants' speech recognition performance in noise was compared across the four participant groups in the language they acquired first. Figure 3 shows the participants' performance on the HINT in noise in their L1. A 2 × 2 (age, language group) between-subjects ANOVA showed significant main effects of language group, $F(1, 57) = 7.1$, $p = .001$, and age, $F(1, 57) = 13.3$, $p = .001$, and a significant interaction between age and language group, $F(1, 57) = 5.36$, $p = .024$. Post hoc testing of pairwise comparisons using a Bonferroni-adjusted critical alpha level showed that the YB participants performed significantly better ($p < .001$) on the HINT in background noise in their L1 compared to all of the other participant groups in this study. This suggests that bilinguals may have an advantage in auditory processing of speech

Figure 3. Mean speech recognition performance scores in signal-to-noise ratio on the Hearing in Noise Test in background noise in participants' first language. Error bars represent ± 1 *SD* from the mean.



information in background noise, but the advantage is attenuated with age.

Self-Reported Assessment of Listening Effort

Participants were asked to self-report the listening effort they expended on the HINT in background noise using a 7-point Likert scale from 0 (*no effort*) to 6 (*extreme effort*). Median self-reported listening effort rating scores for the English HINT in noise were YM 4 (range: 3–5), YB 5 (range: 3–6), OM 4 (range: 3–6), and OB 5 (range: 4–6). Listening effort ratings for the English HINT in background noise were compared using a Kruskal–Wallis one-way ANOVA with the between-subjects factor of group (i.e., YM, YB, OM, and OB). There was a significant difference in listening effort ratings across the four participant groups ($p = .015$). Post hoc testing of the pairwise comparisons for age and linguistic proficiency using Mann–Whitney signed-ranks tests showed a significant difference in listening effort ratings between the monolingual and bilingual participant groups ($p = .003$). That is, bilingual participants reported that listening to the English HINT in noise was more effortful than for the monolingual participants. However, there was no significant difference in listening effort ratings between the younger and older participant groups ($p = .225$).

Bilingual participants rated the listening effort they expended on both the English and Spanish versions of the HINT in background noise. Median self-reported listening effort rating scores were YB 5 (range: 3–6) and OB 5 (range: 4–6) for the English HINT in background noise and YB 3 (range: 3–5) and OB 3 (range: 3–6) for the Spanish HINT in background noise. Listening effort was compared within and across groups using related and independent-samples Wilcoxon signed-ranks tests. Results showed a significant difference in bilinguals' listening effort ratings ($p < .001$) between the English and Spanish versions of the HINT in background noise. Listening effort expended in background noise was less for the Spanish than the English HINT in background noise. However, there was no significant difference in listening effort ratings between the younger and older bilingual participant groups ($p = .9$).

Discussion

In the current study, we examined how speech recognition performance scores and self-reported listening effort changed with age in Spanish–English bilinguals who acquired both of their languages at an early age, and we identified differences in speech recognition performance and self-reported listening effort for bilinguals' L1 and L2. The Spanish–English bilinguals in the current study had significantly poorer English speech recognition performance in background noise compared to the English monolingual participants. However, in quiet, all four participant groups performed at ceiling level (~100% correct) in English. Both groups of bilingual participants self-reported that listening to English speech in background noise was significantly more effortful compared to the monolingual participants in this study. This is despite the fact that the bilingual participants had, on average, received the same number of years of schooling in English and had similar scores on an objective measure of auditory English language proficiency as their monolingual counterparts.

This result is consistent with previous studies that have shown that younger adult English monolinguals perform better than younger adult bilinguals on English speech recognition tests in background noise (Mayo et al., 1997; Rogers et al., 2006; von Hapsburg et al., 2004; Weiss & Dempsey, 2008), even when the bilinguals were equally proficient in both of their languages. In addition, results from the current study provide evidence to support the theory that bilinguals' higher cognitive load, due to one or more factors related to managing two language systems, has a significant effect on English speech recognition performance in background noise, as evidenced by the poorer speech recognition performance scores and higher self-reported listening effort for bilingual speakers compared to their monolingual peers. However, the higher cognitive load for bilinguals did not appear to have an effect on speech recognition performance in quiet listening situations (which had a relatively low cognitive load), even for the older adult Spanish–English bilinguals in the current study, as all participants had excellent English speech recognition scores in quiet.

The older Spanish–English bilinguals had the poorest performance on the English HINT in background noise compared to all the other participant groups in this study. This result is consistent with our hypothesis that older Spanish–English bilinguals are at a greater disadvantage in understanding English compared to OMs due to the additional processing demands they may experience from managing two language systems. Surprisingly, there were no significant differences in self-reported listening effort between the younger and older participant groups in this study. So, although the older bilinguals' performance was significantly poorer than the older monolinguals' performance, the older bilinguals did not perceive the task to be more effortful than the older monolingual listeners did.

Although English speech recognition in noise performance scores were lower for the older bilinguals compared to the older monolinguals, aging did not differentially affect monolingual or bilingual participant groups, as evidenced by the nonsignificant interaction between age and linguistic proficiency. Thus, age-related changes in speech recognition in noise performance were similar for the monolingual and bilingual participants. This result is in contrast to previous studies in the bilingualism literature that have suggested that bilingualism may protect against age-related cognitive declines and dementia due to a long-term positive effect of bilingualism on an individual's selective attention and inhibition of irrelevant information abilities (Bialystok, Craik, Green, & Gollan, 2009; Bialystok, Craik, & Luk, 2008; Mechelli et al., 2004; Stern, 2002).

The bilingual advantage has been explained by the inhibitory control theory of bilingualism, which proposes that bilinguals suppress their nonrelevant language by the executive function used to control attention and inhibition (Green, 1998). Thus, during conversation, a bilingual speaker continually selects one language and rejects another in real time (Bialystok, Craik, Klein, & Viswanathan, 2004). It is thought that bilinguals' constant practice in selective attention and inhibition may provide them with a cognitive advantage over their monolingual peers. Bialystok et al. (2004) investigated processing differences between older monolingual and bilingual individuals using the Simon task, a task that measures executive control processes of inhibitory control. They found that bilingualism reduced the age-related increase in the Simon effect, suggesting that bilinguals' lifelong experience of managing two languages may lessen age-related declines in the efficiency of inhibitory processing.

Considering that selective attention and inhibition of irrelevant information have been found to be significantly associated with listeners' speech recognition in noise performance (Akeroyd, 2008; Desjardins & Doherty, 2013; Gatehouse, Naylor, & Elberling, 2003; Humes, Lee, & Coughlin, 2006), it stands to reason that an advantage in selective attention abilities could lessen the effect of age-related changes on speech recognition in noise performance for older bilinguals compared to older monolinguals. Yet, in the current study, bilingualism did not have a significant effect on age-related changes in speech recognition performance, and the age-related changes in English speech recognition in noise performance were similar between the monolingual and bilingual groups. However, it is possible that we did not find a significant effect due to the relatively simple energetic masking noise used in the current study. Future studies should include informational-type maskers, which have been shown to make speech recognition more cognitively demanding than steady state interference (Desjardins & Doherty, 2013; Helfer & Freyman, 2008), in order to better examine the purported long-term benefits of bilingualism on attention and inhibition of irrelevant information.

Both groups of Spanish–English bilinguals performed significantly better on the Spanish than on the English versions of the HINT in background noise, but performed similarly on the HINT across both languages in quiet. In addition, both groups of bilingual participants self-reported that listening to English speech in background noise was significantly more effortful compared to listening to Spanish speech in background noise. This result is largely consistent with previous studies that have found that even early bilingual participants (i.e., bilinguals who learned both of their languages at an early age) scored significantly better on Spanish than English speech recognition tasks in background noise (e.g., Shi & Sánchez, 2010; Weiss & Dempsey, 2008). This suggests that bilinguals may have a strong connection and reliance on their L1, even when they learned both languages at a very early age. Sebastián-Gallés et al. (2005) contend that an individual's initial exposure to language may be responsible for speech processing differences that persist throughout life between their two languages and that the bilinguals' earliest exposure to language has a profound influence on the way L1 and L2 sounds are perceived. The bilingual participants in the current study were exposed to the Spanish language before the English language, which could explain their better performance on the Spanish HINT despite the fact that they learned both of their languages by the age of 4 years and were highly proficient in both English and Spanish.

To further examine speech recognition in noise performance differences between English monolinguals and Spanish–English bilinguals, we compared participants' speech recognition in noise performance scores on the HINT in noise in their L1 (i.e., Spanish for the bilinguals and English for the monolinguals). These performance scores were representative of each participant's best HINT in noise performance. Interestingly, when the data were compared across groups based on L1 performance, a very different pattern of results emerged as compared to our initial comparison of bilinguals' L2 performance (English) to monolinguals' L1 performance (English) where bilinguals were at an increased disadvantage in understanding speech in background noise. The young bilinguals had significantly better performance on the HINT in background noise in their L1 compared to all of the other participant groups in this study. This suggests that the increased cognitive processing demands of managing two language systems may have differential effects on bilinguals' L1 and L2 (at least for younger bilingual adults) and that younger bilingual adults may have an advantage in processing auditory information in background noise in their L1 compared to older bilinguals and monolinguals.

This result is consistent with Krizman, Marian, Shook, Skoe, and Kraus (2012) who examined Spanish–English bilingual adolescents' (14 years of age) performance on a syllable recognition task in background noise. They found that bilinguals had an advantage in encoding a target sound presented in a noisy background compared to their monolingual counterparts. More recently, Krizman, Bradlow, Lam, and Kraus (2017) found that whereas monolinguals performed better on a sentence in noise task, bilinguals performed better when perceiving tones in noise, and both groups performed similarly when perceiving words in noise. The authors concluded that the bilingual's speech-in-noise disadvantage in understanding speech in their L2 in noise is the result of language-dependent processing. Additionally, the authors suggest that bilinguals may try to compensate for difficulties in linguistic processing by enhancing language-independent processes important for understanding speech in noise.

Results from the current study support the theory that bilinguals' disadvantage in understanding speech in noise in their L2 is the result of language-dependent processing, as evidenced by significant differences in the bilinguals' speech-in-noise performance scores between their two languages. If the underlying mechanism of the bilinguals' disadvantage was independent of language processing, then we would have likely not seen significant differences in bilinguals' performance between the English and Spanish versions of the HINT. However, we contend that bilinguals' enhanced processing (i.e., auditory processing advantage) may not be purely for language-independent measures, as suggested by Krizman et al. (2017). That is, bilinguals may have a language-dependent processing advantage for speech in noise in their L1 (i.e., L1 advantage) compared to monolinguals. Future studies examining bilingual speech recognition performance should include both English and Spanish monolingual control groups, in addition to measures of speech recognition performance in Spanish and English that are equated for difficulty within and across the two languages, in order to gain a more complete understanding of bilinguals' advantages and disadvantages in speech recognition performance.

Currently, there are no standard clinical audiological evaluation and/or treatment protocols for use with older bilingual clients. Thus, older bilingual clients are largely evaluated and treated the same as older monolingual clients in most audiological clinic settings. This is more likely to be true when the older bilingual client appears to be equally proficient in both of their languages and had learned both languages at a very young age (similar to the older bilingual participants in the current study). These bilingual individuals will typically speak English without a foreign accent and are proficient in their reading, writing, and speaking skills in English. Thus, a clinician may not know that their client is bilingual unless they directly asked the individual about their language history and use.

Even if a clinician is aware that their client is bilingual, they may assume that as long as the individual is proficient in English, then they would not need to make any modifications to their existing evaluation or treatment protocols. Results from the current study suggest that a clinician may not need to administer alternative speech recognition test measures in quiet to bilingual clients who are proficient in English. However, it may be indicated that speech-in-noise testing should be administered in the bilinguals' two languages because bilinguals (even those who are proficient in both of their languages) may have significant differences in their speech recognition performance between their L1 and L2. Additionally, Spanish–English bilinguals may also need a modified treatment protocol, due to their increased difficulty understanding speech in background noise compared to older monolinguals.

That is, it may be more strongly indicated for older bilinguals to receive treatment for their hearing loss with hearing aids and assistive listening devices earlier and for those with milder hearing losses to increase performance and reduce listening effort in background noise than for older monolinguals with hearing loss. Also, bilingual clients may require additional or modified counseling and/or aural rehabilitation due to the increased difficulty they may have listening to speech in background noise. Based on the results from the current study, it may also be beneficial for clinicians to recommend that older Spanish–English bilinguals use Spanish (if conducive to the listening situation) when they are in a very difficult listening situation (e.g., noisy restaurant) because it may be less effortful and their performance would likely be better, than if they used English. Future research in this area should focus on clinical studies that examine speech recognition performance and hearing aid treatment protocols in older bilingual adults with different degrees of hearing loss.

Conclusions

Older bilinguals are at a greater disadvantage in understanding English in background noise compared to their monolingual peers. This suggests that current clinical audiological evaluation and treatment procedures may need to be modified to better serve the older Spanish–English bilingual population.

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