JOURNAL OF THE ACADEMY OF REHABILITATIVE AUDIOLOGY

2017, Volume XLX

Research Article

A Pilot Study on the Effects of Nonlinear Frequency Compression on Performance of Individuals Who Speak Mandarin Chinese

Authors

- Suzanne C. Wright
- Arun P. Joshi
- Erin C. Schafer
- Katsura Aoyama
- Tiffany Ho
- Christine Anderson
- Jessalyn Jones
- Jerrica Box

University of North Texas

Department of Audiology and Speech-Language Pathology

Abstract

Purpose

Considering the growth of the culturally and linguistically diverse populations in the United States (U.S.), there is a need to incorporate sensitive, evidence-based assessment tools and treatment options in the hearing care of these populations.

Objectives

The current pilot study investigated the effects of amplification containing Non-linear Frequency Compression (NLFC) on speech perception performance of seven adults who speak Mandarin Chinese (MC) in quiet and in competing background noise. Subjective reports were also measured to examine the relationship between perceived benefit and preferences.

Method

Participants were fitted with receiver-in-the-canal (RIC) style hearing aids for six weeks.

Results

Overall, the results of this pilot investigation indicated that NLFC does not appear to hinder or benefit individuals with hearing loss who speak MC, although some participants reported subjective benefit.

Conclusions

At this time, decisions regarding the use of NLFC should be determined on an individual basis. Moreover, due to the limitations of this study—specifically the limited number of participants, further investigation of the objective and subjective influences of NLFC on speakers of Mandarin Chinese is warranted.

Introduction

Recent hearing aid research has focused on improving the audibility of high-frequency speech sounds, which are often inaudible with traditional high-frequency amplification schematics. One approach to achieving improved high-frequency audibility is the use of frequency-lowering algorithms. Non-linear frequency compression (NLFC) is a type of frequency-lowering processing strategy used to make high-frequency sounds audible by manipulating the output of the spectrum. Specifically, high-frequency sounds are shifted to a lower frequency range than their natural production range. The NLFC algorithms compress high-frequency information into a mid- to low-frequency region below a specified cutoff frequency and maintain normal amplification in lower frequencies.

Traditionally, NLFC is used for individuals who experience speech perception deficits with traditional high-frequency amplification due to insufficient high-frequency audibility in terms of level and bandwidth. Results of several studies support the use of NLFC over traditional amplification for improving speech recognition and sound quality of speech in children and adults with hearing loss who speak English (e.g., McCreery et al., 2014; Parsa et al., 2013; Wolfe et al., 2010). However, to date, there are few, if any, publications examining the effects of NLFC on non-English speakers with hearing loss, particularly those who speak a tonal language. Tonal languages, such as Mandarin Chinese (MC), Vietnamese, and Yoruba, are distinguished by linguistically distinctive tones (i.e., shifts in pitch), which are vital to speech understanding (Chasin, 2008).

Specifically, MC is characterized by four lexically identifiable tones 1) high level, 2) mid rising, 3) low falling, and 4) high falling (Shih, 1988). Although these four tones are not specifically characterized by frequency, the perception of these tones requires an adequate spectral bandwidth, suggestively enhanced by NLFC.

In contrast, these linguistically distinctive tones are not characteristic of non-tonal languages, such as English. Current research indicates improved perception of fricative consonants with the addition of NLFC for native English speakers due to the spectrally diffuse nature of such phonemes (Alexander, 2013). As a result, current speech materials used in the United States (U.S.) to evaluate hearing aid performance may not be appropriate for individuals who speak tonal languages. Additionally, modifications to hearing aid fittings may be necessary to accommodate differences in tonal languages. To that end, the following sections will highlight some of the needs related to the audiological management of individuals who speak MC with hearing loss as well as future implications for management of additional tonal languages.

Demographics

According to the U.S. Census Bureau (2011), long-term and recent historical immigration patterns have increased the language diversity of the country over the past few decades, with 60.6 million people speaking a language other than English at home. Of the 381 languages recognized by the U.S. Census Bureau, Chinese was one of the languages most commonly spoken at home, consisting of 2.5 million speakers in the United States.

Also increasing in magnitude, the "baby boomer" generation will consist of approximately 70 million persons over the age of 65 by 2030, more than twice their number in 2000 (U.S. Department of Health and Human Services, 2002). Approximately 25% of this population is projected to consist of culturally-diverse or minority populations (U.S. Department of Health and Human Services, 2002). One important health consideration for this diverse generation is the presence of hearing loss in approximately one in three individuals' ages 65 to 74 years (U.S. Department of Health and Human Services [HHS], National Institutes of Health [NIH], National Institute on Deafness and Other Communication Disorders [NIDCD], 2016). As hearing impairment is one of the most chronic conditions affecting this age range, evidence-based hearing healthcare will be required to serve the influx of individuals over the age of 65 years, including those of various ethnicities and languages.

Audiological Management

The most common management approach for individuals with hearing loss is the use of traditional amplification (i.e., hearing aids). Recent hearing aid research has focused on improving the audibility of high-frequency speech sounds (> 4000 Hz), which are often inaudible with traditional high-frequency amplification schematics. One approach to achieving improved high-frequency audibility is the use of frequency-lowering algorithms, which compress or move high-frequency information into a mid- to low-frequency region where an individual's auditory system will be able to interpret auditory stimulation below a specified cutoff frequency as well as maintain normal amplification in lower frequencies. Previous studies that have investigated the benefits of NLFC have produced mixed results in adults. For example, Simpson et al. (2006) examined the effects of NLFC on adult listeners with steeply sloping audiograms and found no significant benefit in speech recognition performance, in quiet and in noise, when comparing NLFC and traditional amplification. Despite that, the investigators reported that subjective preference for the sound quality was evidenced for traditional amplification. In another study, Picou, Marcrum, and Ricketts (2015) examined speech recognition and sound quality ratings with and without NLFC in 17 adult listeners with mild to moderate sensorineural hearing loss. Average results suggested that NLFC improved recognition of the phoneme /s/, but no effect of NLFC on consonant discrimination thresholds, consonant recognition, sentence recognition in noise, or sound quality ratings. In a similar study, Hopkins, Khanom, Dickinson, and Munro (2014) reported that, on average, adults with mild to profound sensorineural hearing loss had improved consonant recognition in quiet, but speech recognition did not improve in noise. More recently, Ellis and Munro (2015) investigated benefit obtained by NLFC in 12 experienced adult hearing aid users with moderate to severe sensorineural hearing loss. Their findings demonstrated that participants obtained benefit from NLFC on all measures of speech perception on a group level. In particular, the results indicated significant improvements in speech and consonant recognition performance, both in quiet and in noise.

Results that included both children and adults also produced variable results across test measures. For instance, Glista et al. (2009) evaluated consonant, vowel, and speech recognition as well as preference ratings with NLFC in 13 adults and 11 children with various degrees of hearing loss ranging from moderate to profound. Across the age groups, results showed that, relative to traditional amplification, NLFC improved perception of high-frequency phonemes (i.e., /s/, /ʃ/) and consonants, but did not improve vowel recognition.

Additionally, NLFC was preferred by the children, but not by the adults. In another study, McCreery et al. (2014) examined the influence of NLFC on word recognition scores in 24 adults and 12 children with varying degrees of hearing loss. The results suggested an average improvement with NLFC for both children and adults, with all but two participants showing individual improvements with NLFC. Most recent research with children indicates average benefits from the use of NLFC (Wolfe et al., 2010; 2011).

Although the results of these investigations have, for the most part, supported the use of NLFC in children and adults with hearing loss who speak English, some authors found considerable variance in outcomes at the individual level (Ellis & Munro, 2015; Glista et al., 2009) and others did not (McCreery et al., 2014). The difference in outcomes could be due to a number of reasons, including variations in the duration of the acclimatization period, degree and configuration of high frequency hearing loss, and frequency compression fitting parameters.

As for subjective preferences, Glista and colleagues (2009) suggested that individual preference for NLFC was related to age group and benefit, such that those people who benefit the most were more likely to prefer NLFC. Ellis and Munro (2015) also reported on the relationship between self-reported benefit and performance with NLFC; however, their findings indicated marginal difference in subjective ratings between NLFC and traditional amplification.

Due to the limited publications on the effect of NLFC on non-English speakers with hearing loss, additional investigation is warranted. In particular, it is possible that the use of NLFC would result in differing patterns of speech-recognition performance in speakers of languages that consist of tonal (i.e., frequency) shifts to convey meaning, such as speakers of MC, because the NLFC intentionally compresses the high-frequency consonant information into a mid- to low-frequency region. The NLFC could improve speech recognition because of the improved audibility of high-frequency phonemes, consequently improving audibility of the linguistic tones (i.e., high level, mid rising, and high falling) and overall semantics. However, for listeners with less severe high frequency hearing loss, NLFC may not affect speech recognition performance in speakers of MC relative to traditional amplification because many of the tonal shifts occur with vowels in the lower-frequency regions, which are unaffected by NLFC (Hua, 2007; Kratochvil, 1998). Additionally, one type of amplification may be beneficial when listening to MC speakers, but another type of amplification might be helpful when listening to English speakers. Because of the linguistic differences in MC versus English, it is not possible to extend research data from individuals who speak English to those who speak MC (McCreery et al., 2014). Therefore, it is imperative to establish evidence regarding the most appropriate type of amplification, traditional or NLFC, for individuals with hearing loss who speak MC to provide optimal hearing for effective communication. For both Mandarin- and English-speaking individuals, inappropriately activating NLFC can reduce the frequency response of amplification, resulting in detriments to speech perception. In particular, pediatric and first-time hearing aid users may not be able to report on the reduced audible bandwidth and the associated deleterious effects on speech perception abilities.

Study Aims and Overview

The primary goal of this pilot study is to examine the effects of NLFC on the behavioral performance of individuals who speak MC. Aforementioned investigations included English-speaking individuals, whereas the current study examines individuals who speak a tonal language. Subjective preference data comparing NLFC to traditional amplification preferences were documented. Behavioral measures were conducted with traditional amplification and NLFC, in MC and English, using speech recognition, with and without noise, and Mandarin tone identification.

Methods

Participants

The University of North Texas (UNT) Institutional Review Board approved the methods and procedures for this pilot study. Participants were recruited through flyers posted in the UNT Speech and Hearing Center, as well as social groups throughout the Dallas-Fort Worth Metroplex. Participants were required to attend two test sessions and were financially compensated following each session. Hearing aids were provided and verified for all participants, including current hearing aid users. The following inclusionary criteria were used: (1) MC as the primary language, (2) high frequency pure tone average (PTA) greater than 25 dB HL, and (3) no medical contraindications for the use of hearing aids. Written informed consent was obtained from all participants. Participants in the study were seven adults who ranged in age from 32 to 82 years (M = 62.9; SD = 15.8], all with self-reported hearing loss. In Table 1, hearing ability was summarized using a traditional PTA (average threshold for .5, 1, and 2 kHz) and high frequency PTA (average threshold for 1, 2, and 4 kHz) for each ear. Five participants presented with bilateral sensorineural hearing loss (SNHL), one with mixed hearing loss, and one with unilateral conductive hearing loss. The average hearing thresholds for each ear are shown in Figure 1.

Table 1. Participant Demographic Information.

1	32	R: 3	R: 3
		L: 40	L: 40
2	57	R: 28	R: 42
		L: 22	L: 22
3	82	R: 88	R: 83
		L: 47	L: 47
4	74	R: 42	R: 48
		L: 40	L: 40
5	68	R: 32	R: 33
		L: 28	L: 28
6	69	R: 42	R: 52
		L: 42	L: 42
7	63	R: 55	R: 65
		L: 45	L: 45

Note. HF=high frequency; L= left; R=right; PTA=pure tone average.

Three participants were current hearing aid users, and the remaining four participants were first-time hearing aid users. Of the three current hearing aid users, one participant wore digital, receiver-in-the-canal style hearing aids, and one participant wore a unilaterally-fit digital hearing aid. All participants spoke MC as their primary language and English as their non-native language. A preliminary audiological evaluation was conducted to ensure the participant satisfied the hearing loss requirement for participation in the study.

Equipment

All participants were fitted with Phonak Audeo V90-13 receiver-in-the-canal (RIC) hearing aids, appropriately measured Phonak receivers, and Phonak-recommended SlimTip domes. Real-ear verification-measures were conducted with the Audioscan Verifit (Dorchester, Ontario) and are described in the following section.

Behavioral testing was conducted in a double-walled sound booth. Test stimuli were presented with an audiometer (GSI 61; Eden Prairie, MN), Sony Compact Disc Player (CDP-CE500), laptop computer, and two single-coned loudspeakers located

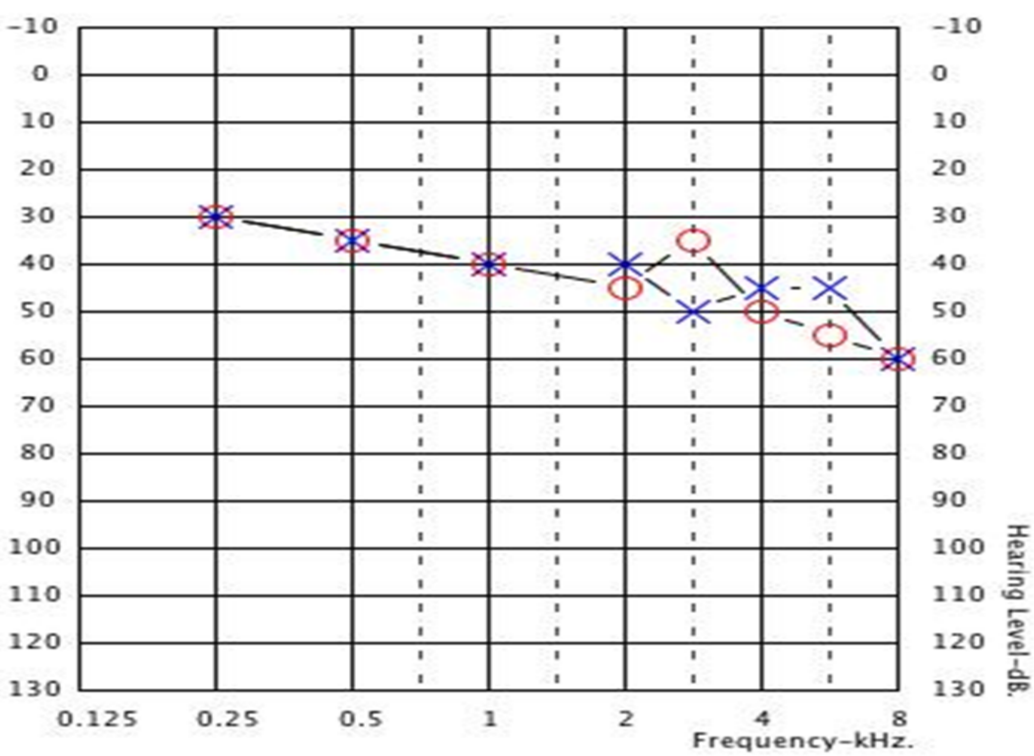

Figure 1. Average audiometric thresholds of all participants by ear. Note. The audiogram was created with http://audiogrammaker.com, Haskins, J. (2015).

at 0 (speech) and 180 degrees (noise) azimuth (Grason Stadler Standards). The participant was seated 3.54 feet (1.07 m) from each head-level loudspeaker. Pure-tone audiometry was conducted with the same audiometer and insert earphones (TDH-39). Calibration and stimuli intensity were determined using a sound-level meter (Larson-Davis 824, Depew, NY).

Hearing Aid Fitting Procedures

Hearing aid evaluations were performed for each participant. The test battery included: otoscopy, tympanometry, and pure-tone audiometry. Prior to the first appointment, lab personnel confirmed proper device function by performing a listening check. Participants were fitted with Phonak RIC devices using clinically appropriate receiver wire length, receiver power, and dome style. All devices were fitted and verified using real ear unaided gain response techniques via an AudioScan Verifit and a 2-cc coupler, using each individual participant's measured real-ear-to-coupler difference (RECD). Two programs were saved to the hearing instruments, which included an automatic program with NLFC turned on and an automatic program with NLFC turned off. During the fitting, the hearing aid outputs for both programs were matched to NAL-NL2 (Keidser et al., 2011) output targets for 65 and 75 dB inputs, and the acclimatization level was set at 100%. Any participant complaints of sound quality were addressed with the automatic fine-tuning option. The volume control was enabled to promote acclimatization to the hearing aid settings, if necessary, and to circumvent further adjustments. The program button was also enabled to facilitate program switching, per the study protocol described in the following paragraph. Additionally, the data logging option was used to determine how often the participants wore the hearing aids, and if they successfully switched programs when required. Participants were counseled appropriately on device use and care. Participants were asked to demonstrate capability of manipulating the program button, and hard copies of the instructions were also given to them to supplement the counseling session.

Participants were required to switch their program to either NLFC or traditional every week. Participants were given a journal to rate their listening experience each week; the journal also served as a reminder to switch programs accordingly. Participants were blind to the program in use during any given week because the order of the programs (i.e., Program 1 and Program 2) was counterbalanced across participants. Participants were also asked to select their program preference at the end of the trial.

Procedures and Study Design

Participants were tested across two test sessions. In Session 1, participants completed the comprehensive audiological assessment; the hearing device fitting (counterbalanced order of programs: Program 1: NLFC off; Program 2: NLFC on); and counseling on the device, trial period. A simplified hearing aid user guide was discussed and distributed to all participants. The user guide offered basic descriptions on how to differentiate the right from the left hearing aid, how to put the hearing aid on, how to turn the hearing aid off and on, how to change the volume, how to change the program, and other basic maintenance instructions. The investigators found it necessary to provide detailed instructions specific to device care and use because some participants were new hearing aid users.

Table 2. Individual Scores for Speech Recognition Measures.

Subject	HINT (Quiet)		HINT (Noise)		M-HINT (Quiet)		M-HINT (Noise)	
Hearing Aid Condition	TR	FC	TR	FC	TR	FC	TR	FC
1	29	31	-7	-7	27.5	23.5	-6.5	-7.7
2	35.5	41.6	-2	-6.5	40.5	37.2	-4.6	-3.6
3	63.2	72.5	14.6	14.9	39	49.2	1.1	2.1
4	38.6	44.5	4.4	5.5	45.8	42.4	-5	-8.2
5	35.1	35.8	3.8	-9.4	48.9	34.5	-12	-12.6
6	36	42.2	-3.9	-2.7	36.8	45.8	-0.2	-4.2
7	DNT	DNT	DNT	DNT	46.11	45.8	-2.5	-2.3

Note. DNT=did not test; FC=Frequency Compression; HINT=Hearing in Noise Test; M=Mandarin; TR=Traditional.

Participants were encouraged to contact the investigators with any questions or concerns to facilitate accurate compliance during the study. In Session 2, participants completed the aforementioned behavioral test measures, and the examiners also documented the subjective preferences of the participants.

A within-subject, repeated measures design was used to compare performance from the behavioral test measures with the traditional and NLFC amplification. Individual data were also examined given the small sample size and range of hearing loss configurations.

Behavioral Measures

Following behavioral testing in session 1, participants returned after six weeks of hearing aid use for their second session. The participants were tested using traditional and NLFC amplification in the following conditions: (1) English speech recognition in quiet and in the presence of adaptive background noise, (2) MC Speech recognition in quiet and in the presence of adaptive background noise, (3) phoneme detection and perception, and (4) tone identification. Speech recognition was evaluated in English and MC to determine if NLFC was beneficial when listening to talkers in one or both languages.

English Speech Recognition. For the English speech-recognition task, participants completed the Hearing in Noise Test (HINT) (Nilsson, Soli, & Sullivan, 1994) in the following conditions: (1) NLFC active, Quiet; (2) NLCF active, Noise; (3) Traditional Amplification, Quiet; (4) Traditional Amplification, Noise. The HINT consists of sentences recorded in quiet, with the option to add speech-shaped noise. According to Nilsson et al. (1994), the noise source was developed by using the mean-squared level of each digitally recorded sentence, and the sentences are, for the most part, equally intelligible when presented in the spectrally matched noise.

In the quiet condition, the starting presentation level for the HINT was 60 dBA, and the stimuli was presented through speaker with the speech source at 0° in front of the participant. The presentation level was adaptive and was dependent on the participant's response, until 20 sentences were completed. For the first four sentences, the presentation level was raised or lowered by 4 dB steps. For sentences 5-21, the presentation was raised or lowered by 2 dB steps. The participant was instructed to repeat anything they heard, even if it was only part of the sentence. The reception threshold for sentences (RTS) was then calculated, otherwise known as the HINT Threshold or HINT Score in dBA, by adding the presentation levels of Sentences 5-21 and dividing by 17. The RTS is the presentation level at which half the sentences are correctly recognized. The participant was then asked to change their program from Program 1 to Program 2 and given another HINT Sentence List.

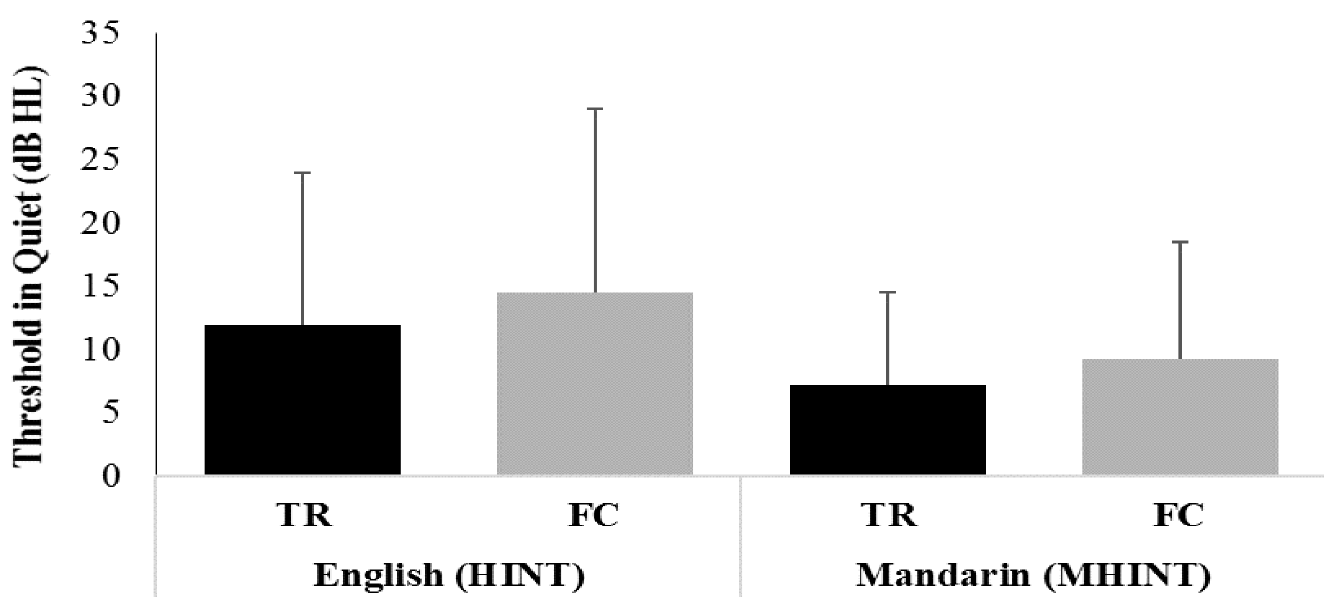

Figure 2. Average speech recognition thresholds in quiet with vertical bars representing one standard deviation. Note. HINT=Hearing in Noise Test. TR= Traditional. FC= Frequency Compression. M=Mandarin.

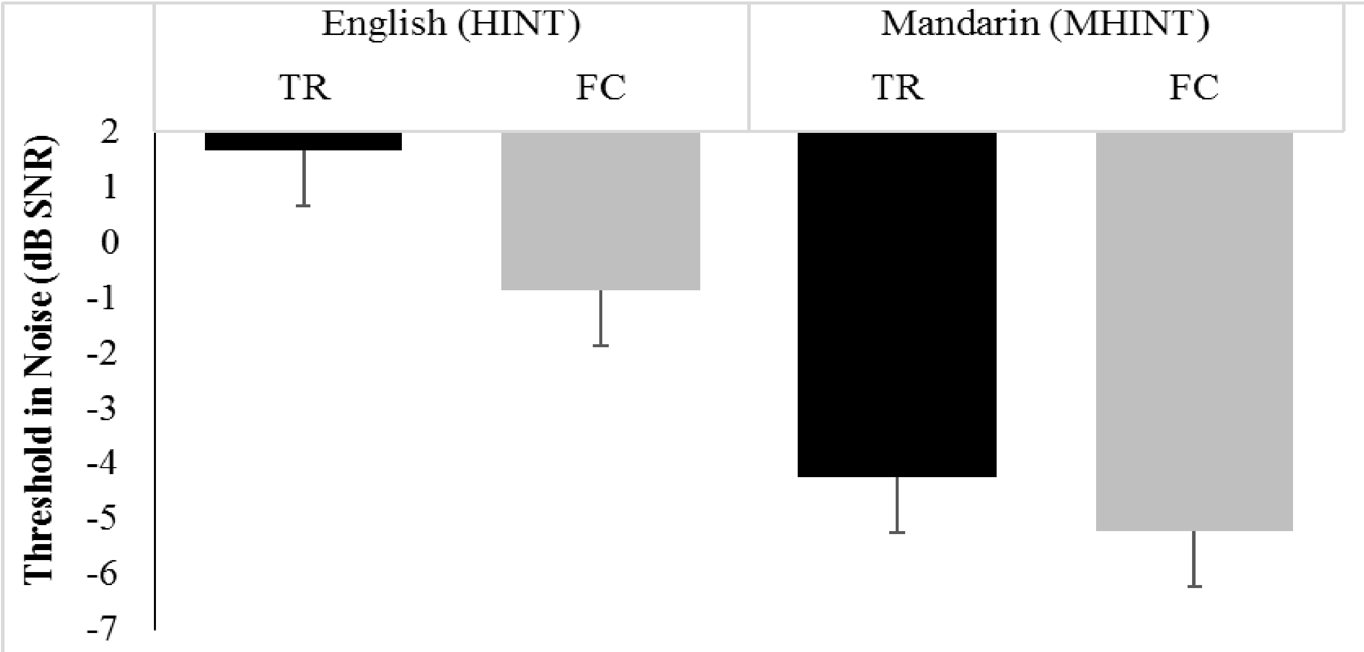

Figure 3. Average speech-in-noise thresholds with vertical bars representing one standard deviation. Note. HINT=Hearing in Noise Test. TR=Traditional. FC=Frequency Compression. M=Mandarin.

For the noise condition, the speech stimuli were presented through a speaker 0° in front of the participant, and the noise stimuli was presented through a speaker 180° behind the participant. The starting presentation level was 60 dBA for the speech stimuli and 57 dBA for the noise stimuli. The same adaptive procedure was used in the noise condition as the one described for the quiet condition, with the noise constant at 57 dBA, and the scoring procedure for quiet and noise conditions was identical.

Mandarin Speech Recognition. For the MC speech-recognition task, the Mandarin Hearing in Noise Test (MHINT) (Wong et al., 2007), participants completed the same four test conditions with and without NLFC in quiet and in noise. The MHINT consists of sentences recorded in quiet, with the option to add a noise source spectrally matched to the average spectrum of the sentences. Procedures and scoring for the MHINT were identical to those described for the HINT. For each participant, a Mandarin-speaking research assistant was present in order to administer and score the MHINT.

Phoneme Detection and Perception. Phoneme detection and perception was evaluated using the Phonak Phoneme Perception Test 2.1 (2014). The Phonak Phoneme Perception Test 2.1 is a computer-based, language independent speech test used to provide information on the hearing aid's settings for gain and frequency-lowering. The test incorporates three tests for the assessment of the participant's abilities in 1) detecting, 2) recognizing, and 3) distinguishing. The detection test is similar to a free-field audiogram where the participant is situated in the sound booth, facing a speaker and a computer monitor. The computer monitor is wired to a laptop, controlled by the tester. The tester manipulates the software on the laptop, based on the participant's response. The participant is instructed to raise their hand whenever a sound becomes audible. The phonemes used for this portion include: /ʃ/ weighted at 3k Hz, /ʃ/ weighted at 5k Hz, /s/ weighted at 6k Hz, and /s/ weighted at 9k Hz. The distinction test presents four varying high-frequency phonemes, and the participant must select which of the four phonemes differs from the other three. When the noise is presented, the four phonemes are displayed on the computer screen, and the participant is asked to report the number associated with the phoneme. If the participant is unable to respond in English, a portable white board was provided for the participant to write the associated number. The final assessment, the recognition test, measures the participant's ability to recognize high frequency speech sounds (e.g., /ʃ/ and /s/). The phonemes are embedded in a pair of vowels, forming non-sense words like /aʃa/. The participant asked to designate which speech sound was presented in the middle of the word with a verbal response or on the white board.

Table 3. Individual Scores for the Phoneme Perception Test (dB HL).

Subject	Detection								Recognition							
Stimuli & Frequency	/ ʃ / 3k Hz		/ ʃ / 5k Hz		/S/ 6k Hz		/S/ 9k Hz		/S/ 3k Hz		/ ʃ / 5k Hz		/S/ 6k Hz		/S/ 9k Hz	
Hearing Aid Condition	TR	FC	TR	FC	TR	FC	TR	FC	TR	FC	TR	FC	TR	FC	TR	FC
1	25	25	25	25	25	25	35	37.5	45	20	40	25	30	30	45	35
2	35	35	37.5	35	50	50	NR	60	32.5	32.5	35	40	45	45	NR	65
3	25	25	25	25	25	25	25	25	32.5	37.5	32.5	35	32.5	40	40	25
4	25	25	25	25	30	30	67.5	50	22.5	27.5	27.5	25	35	32.5	75	57.5
5	30	30	25	30	25	25	40	25	32.5	45	37.5	40	37.5	27.5	55	27.5
6	27.5	25	25	25	25	25	50	45	42.5	40	40	40	27.5	25	47.5	40
7	25	25	25	25	25	25	25	25	40	40	40	40	30	30	35	35

Note. FC=Frequency Compression; NR=No Response; TR=Traditional.

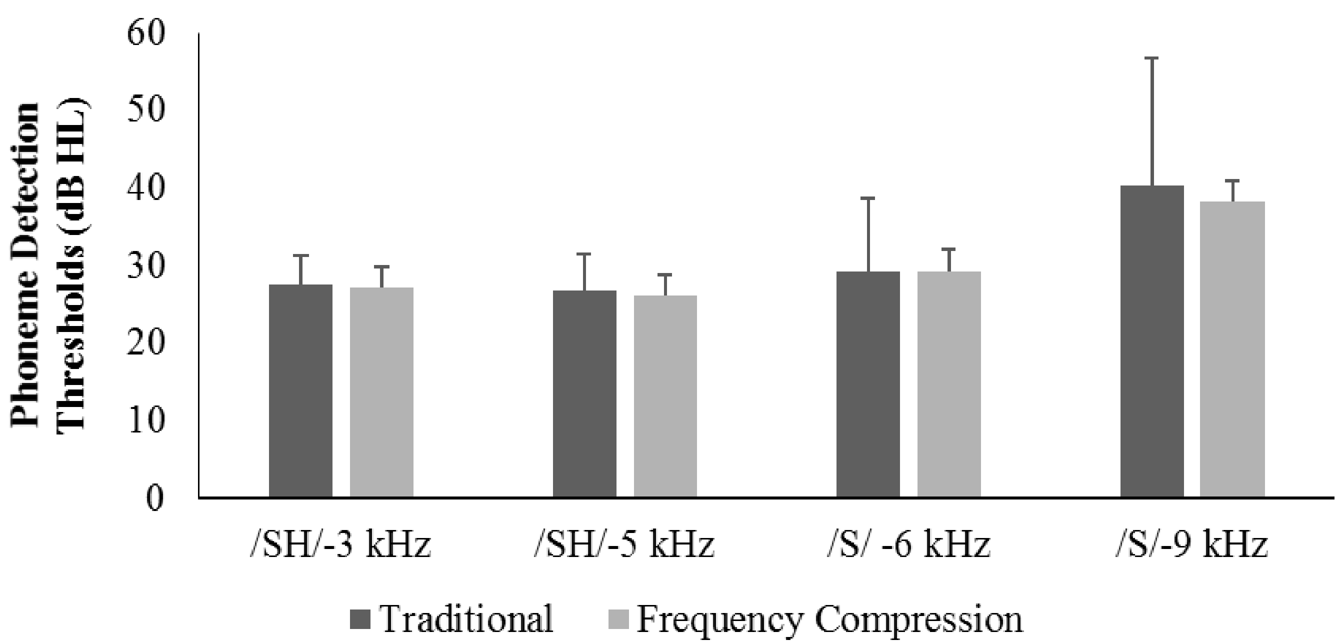

Figure 4. Average phoneme detection thresholds with vertical bars representing one standard deviation.

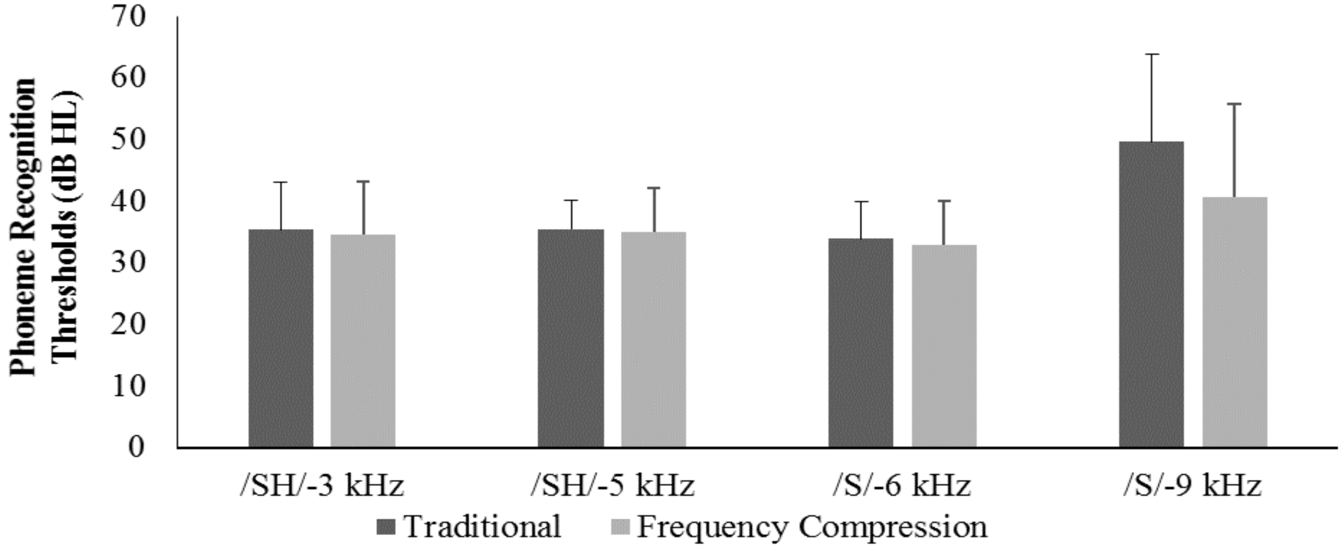

Figure 5. Average phoneme recognition thresholds with vertical bars representing one standard deviation.

Mandarin Tone Recognition. Mandarin tone recognition was evaluated with the computer-based, Mandarin Tone Identification Test (closed set; Krenmayr et al., 2011). The test is administered twice, once with the participant's Program 1 setting and again with the participant's Program 2 setting. The test procedures are similar to the previously mentioned computer-based Phonak Phoneme Perception Test. The participant is facing a speaker and a computer monitor, and the monitor is wired to a laptop, which is controlled by the tester. The participant is instructed that he or she will hear tones that correspond to one of the words on the screen. Following the auditory tone stimulus, the tester moved the mouse pointer over each response. The participants were asked to respond, "yes", when the correct word they heard is highlighted with the pointer. The tester, then, selected the response. Eighty test words were used for each of the program conditions.

Table 4. Individual Scores for the Tone Identification (% correct)

Subject	Traditional	Frequency Compression
1	100	100
2	96.25	95
3	76.25	77.5
4	67.5	68.75
5	67	60
6	65	66.25
7	71.25	86.25

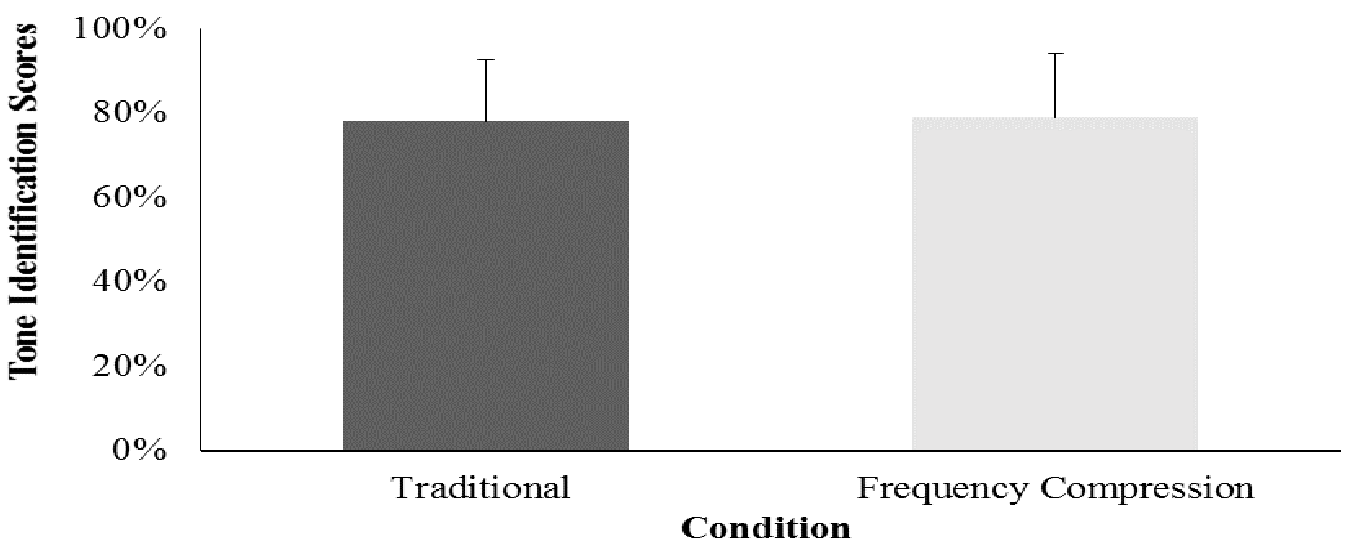

Figure 6. Average tone identification score with vertical bars representing one standard deviation.

Results

Behavioral Measures

Individual speech recognition scores in quiet on the HINT and MHINT are included in Figure 2 and Table 2. One of the participants (Participant 7) could not reliably complete the speech recognition conditions in English; as a result, there are only six participants who completed the HINT in quiet and noise.

A separate one-factor repeated measures analysis of variance (RM ANOVA) was used to compare performance with the traditional and NLFC amplification for the HINT and the MHINT data. The analyses on the HINT in quiet revealed significantly lower (better) thresholds with the traditional amplification over the NLFC ($F [1,12] = 15.4$, $p = .01$). However, the analysis on the MHINT in quiet showed no significant difference between conditions ($F [1,14] = .02$, $p = .89$).

The average speech recognition in noise is shown in Figure 3. The RM ANOVA on the HINT in noise and also the MHINT in noise suggested no significant differences between the two types of amplification ($F [1,12] = 1.2$, $p = .32$; $F [1,14] = 1.7$, $p = .24$, respectively).

Average detection and recognition thresholds on the phoneme perception test are shown in Figures 4 and 5, respectively. These data were analyzed with a two-factor RM ANOVA with the independent variables of amplification condition (traditional; NLFC) and stimulus (ʃ-3k Hz; ʃ-5k Hz; s-6 k Hz; s-9 k Hz). The analysis on the detection thresholds showed no significant difference across amplification condition ($F [1,55] = .11$, $p = .74$), a significant difference across stimulus condition ($F [3,55] = 5.6$, $p = .002$), and no significant interaction effect between amplification and stimulus conditions ($F [3,55] = .04$, $p = .99$). To examine the significant main effect of stimulus, a Tukey-Kramer Multiple Comparisons Test was conducted and revealed a significantly higher (poorer) average threshold ($p < .05$) for the /s/ stimulus at 9000 Hz when compared to all remaining stimuli. The RM ANOVA on the recognition thresholds yielded similar results: no significant difference across amplification condition ($F [1,55] = 1.35$, $p = .25$), a significant difference across stimulus condition ($F [3,55] = 4.3$, $p = .009$), and no significant interaction effect between amplification and stimulus conditions ($F [3,55] = .59$, $p = .62$). The post-hoc analysis on the interaction effect, again, suggested a significantly higher average threshold ($p < .05$) for the /s/ stimulus at 9000 Hz when compared to all remaining stimuli.

The average tone identification performance is shown in Figure 6. These data were analyzed with a one-factor RM ANOVA with the independent variable of amplification type. The analysis revealed no significant main effect of amplification type ($F [1,14] = .36$, $p = .57$).

Following completion of the journal questions, the examiner asked the participants if they had a program preference. Overall, the participants did not indicate a strong preference for either the traditional or NLFC program. To that end, participants one and three did indicate a slight preference for the traditional program. Conversely, participant seven described the NLFC program as much better than the traditional program.

Discussion

Overall, the use of NLFC did not appear to hinder or benefit individuals with hearing loss who speak MC. In quiet, there were no differences in speech recognition performance in English and MC. Conversely, in noise, speech recognition in English was substantially poorer than performance in MC, which supports previous investigations (Crandell & Smaldino, 1996; Jin & Liu, 2012; Warzybok, Brand, Wagener, & Kollmeier, 2015) illustrating poor performance in noise for a non-native language. Moreover, behavioral results showing no differences between types of amplification are likely related to the variability in the degree of hearing losses in our participants. To that end, a larger and more homogenous sample of participants will be needed to examine further behavioral performance with NLFC. In particular, future investigations may benefit by examining individuals with and without previous hearing aid experience in separate groups.

The anecdotal reports of preference yielded a considerable amount of variability in responses among subjects. The subjective preference data indicated that four participants had no preference for either program, two preferred the traditional program and one preferred the NLFC program. These findings are essentially consistent with Ellis and Munro (2015) who reported that the benefit obtained by frequency compression to speech perception might not be reflected in subjective measures. The investigators hypothesize that the variations in preferences could be related to hearing aid experience, as three of the participants were previous hearing aid users. Thus, as mentioned above, future investigations may benefit by investigating these two groups separately.

In general, further research should be conducted to detail hearing aid fittings per specific languages, especially in the U.S. due to the multicultural influence. In the future, hearing aid programs may be utilized for participants to manipulate their amplification scheme as they converse in different languages.

Because of the results of the study are inconclusive, the potential benefit of NLFC will need to be determined on an individual basis.

Conclusion

Results of this pilot investigation demonstrate that NLFC does not appear to hinder or benefit individuals with hearing loss who speak MC. Speech recognition measures, in English and MC, showed significant benefit of traditional amplification, compared to NLFC in quiet, but no difference between conditions in noise. Per individual, speech-in-noise scores measured in English were poorer than speech-in-noise scores obtained in MC, due to second language learning effects. The type of amplification had no effect on tone detection and recognition measures, conducted in English or MC. However, further research is warranted given the limited number of participants in this pilot study. In addition, the varying audiological background of the participants could have been a contributing factor to the varying results. Contributing factors include, but are not limited to the following: duration of prior hearing aid use, duration of hearing loss, type or configuration of hearing loss (sensorineural versus. conductive; bilateral versus unilateral). As a result, when considering amplification schemes for Mandarin speakers, frequency-lowering strategies, such as NLFC should be considered when speech recognition measures or user preference support its use.

References

Alexander J.M. (2013). Individual variability in recognition of frequency-lowered speech. *Seminars in Hearing, 34,* 86-109.

Chasin, M. (2008). How hearing aids may be set for different languages. *Hearing Review, 15(11),* 16-20.

Ellis, R.J. & Munro, K.J. (2015). Benefit from, and acclimatization to, frequency compression hearing aids in experienced adult hearing-aid users. *International Journal of Audiology, 54,* 37-47.

Glista, D., Scollie, S., Bagatoo, M., Seewalk, R., Vijay, P., & Johnson, A. (2009). Evaluation of nonlinear frequency compression: Clinical outcomes. *International Journal of Audiology, 48(9),* 632-644.

Haskins, J. (2015). AudiogramMaker (Version R2015531). Retrieved from http://audiogrammaker.com

Hopkins, K., Khanom, M., Dickinson, A.M., & Munro, K.J. (2014). Benefit from non-linear frequency compression hearing aids in a clinical setting: the effects of duration of experience and severity of high-frequency hearing loss. *International Journal of Audiology, 53(4),* 219-228.

Hua, Z. (2007). Putonghua (modern standard Chinese) speech acquisition. In S. McLeod (Ed.), *The International Guide to Speech Acquisition (pp. 516-527).* Clifton Park, NY: Thomson Delmar Learning.

Jin, S. H., & Liu, C. (2012). English sentence recognition in speech-shaped noise and multi-talker babble for English-, Chinese-, and Korean-native listeners. *Journal of the Acoustical Society of America, 132(5)*:EL391-7.

Keidser, G., Dillon, H., Flax, M., Ching, T., & Brewer, S. (2011). The NAL-NL2 prescription procedure. *Audiology Research, 1(1)*, e24.

Kratochvil, P. (1998). Intonation in Beijing Chinese. In D. Hirst & A. Di Cristo (Eds.), *Intonation Systems: a Survey of Twenty Languages (pp. 417-431).* Cambridge, UK: Cambridge University.

Krenmayr, A., Qi, B., Liu, B., Liu, H., Chen, X., Han, D., ... & Zierhofer, C. M. (2011). Development of a Mandarin tone identification test: Sensitivity index d'as a performance measure for individual tones. *International Journal of Audiology, 50(3),155-163.*

McCreery, R., Alexander, J., Brennan, M.A., Hoover, B., Kopun, J., & Stelmachowicz, P. (2014). The influence of audibility on speech recognition with nonlinear frequency compression for children and adults with hearing loss. *Ear & Hearing, 35(4), 440-447.*

Nilsson, M., Soli, S., & Sullivan, J. (1994). Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America 95(2): 1085-99.*

Parsa, V., Scollie, S., Glista, D., & Seelisch, A. (2013). Nonlinear frequency compression: Effects on sound quality ratings of speech and music. *Trends in Amplification, 17(1), 54-68.*

Phonak, A. G. (2014). Phoneme Perception Test 2.1.

Picou, E. M., Marcrum, S. C., & Ricketts, T. A. (2015). Evaluation of the effects of nonlinear frequency compression on speech recognition and sound quality for adults with mild to moderate hearing loss. *International Journal of Audiology, 54 (3), 162-169.*

Shih, C. (1988). Tone and intonation in Mandarin. *Working Papers of the Cornell Phonetics Laboratory, 3, 83-109.*

Simpson, A., Hersbach, A.A., & McDermott, H.J. (2006). Frequency-compression in listeners with steeply sloping audiograms. *International Journal of Audiology, 45, 619-629.*

Warzybok, A., Brand, T., Wagener, K. C., & Kollmeier B. (2015). How much does language proficiency by non-native listeners influence speech audiometric tests in noise? *International Journal of Audiology, 54 Supplemental 2*, *88-89*.

Wolfe, J., John, A., Schafer, E., Nyffeler, M., Boretzki, M., & Caraway, T. (2010). Evaluation of nonlinear frequency compression for school-age children with moderate to moderately severe hearing loss. *Journal of the American Academy of Audiology, 21(10)*, *618-628*.

Wolfe, J., John, A., Schafer, E., Nyffeler, M., Boretzki, M., Caraway, T., & Hudson, M. (2011). Long-term effects of non-linear frequency compression for children with moderate hearing loss. *International Journal of Audiology, 50*, *396-404*.

Wong, L. L., Soli, S. D., Liu, S., Han, N., & Huang, M. W. (2007). Development of the Mandarin hearing in noise test (MHINT). *Ear and hearing, 28(2), 70S-74S*.

U.S. Census Bureau. (2011). Language use in the United States: 2011 [American Community Survey Reports]. Retrieved from http://www.census.gov/prod/2010pubs/acs-12.pdf.

U.S. Department of Health and Human Services, Administration on Aging, (2002). *A profile of older Americans: 2002*. Retrieved from http://www.aoa.gov/AoAroot/Aging_Statistics/Profile/2002/2.aspx.

U.S. Department of Health and Human Services, National Institutes of Health, National Institute on Deafness and Other Communication Disorders. (2016). *Age-related hearing loss (NIH Publication No. 97-4235)*. Retrieved from https://www.nidcd.nih.gov/health/age-related-hearing-loss

Correspondence

Erin C. Schafer

University of North Texas

Department of Speech and Hearing Sciences

E-mail: Erin.Schafer@unt.edu

Phone: (940) 369-7433

Fax: (940) 565-4058