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Research Article

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

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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

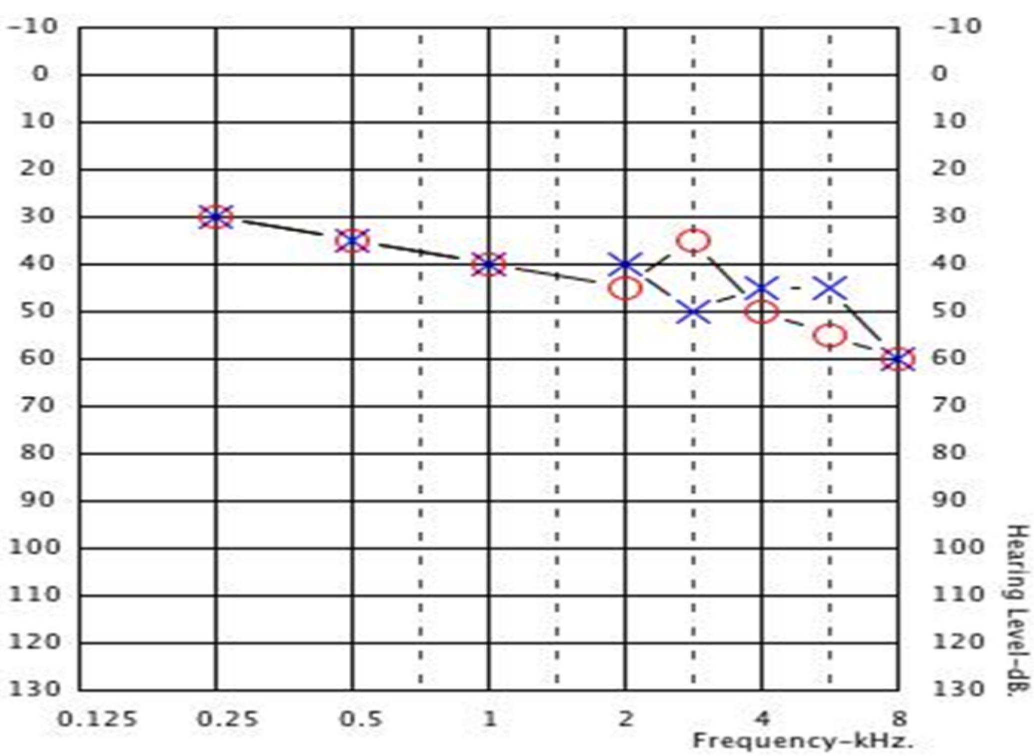

Figure 1. Average audiometric thresholds of all participants by ear. Note. The audiogram was created with http://audiogrammaker.com, Haskins, J. (2015).

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.

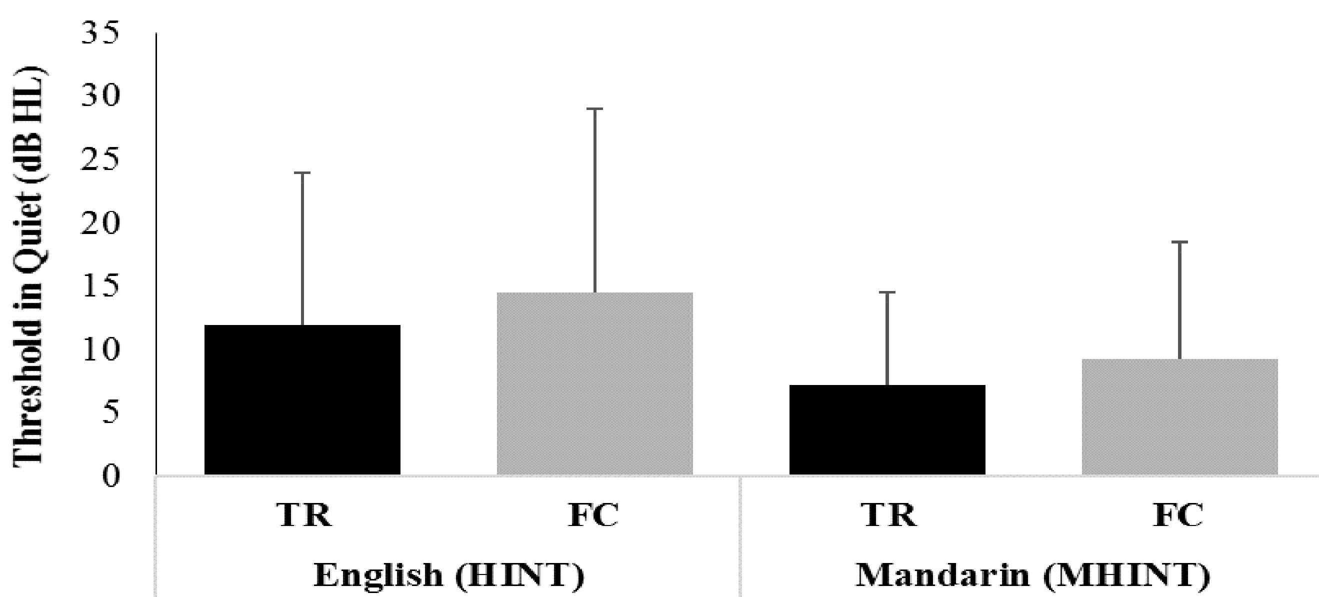

Figure 2. Average speech recognition thresholds in quiet with vertical bars representing one standard deviation. Note. HINT=Hearing in Noise Test. TR= Traditional. FC= Frequency Compression. M=Mandarin.

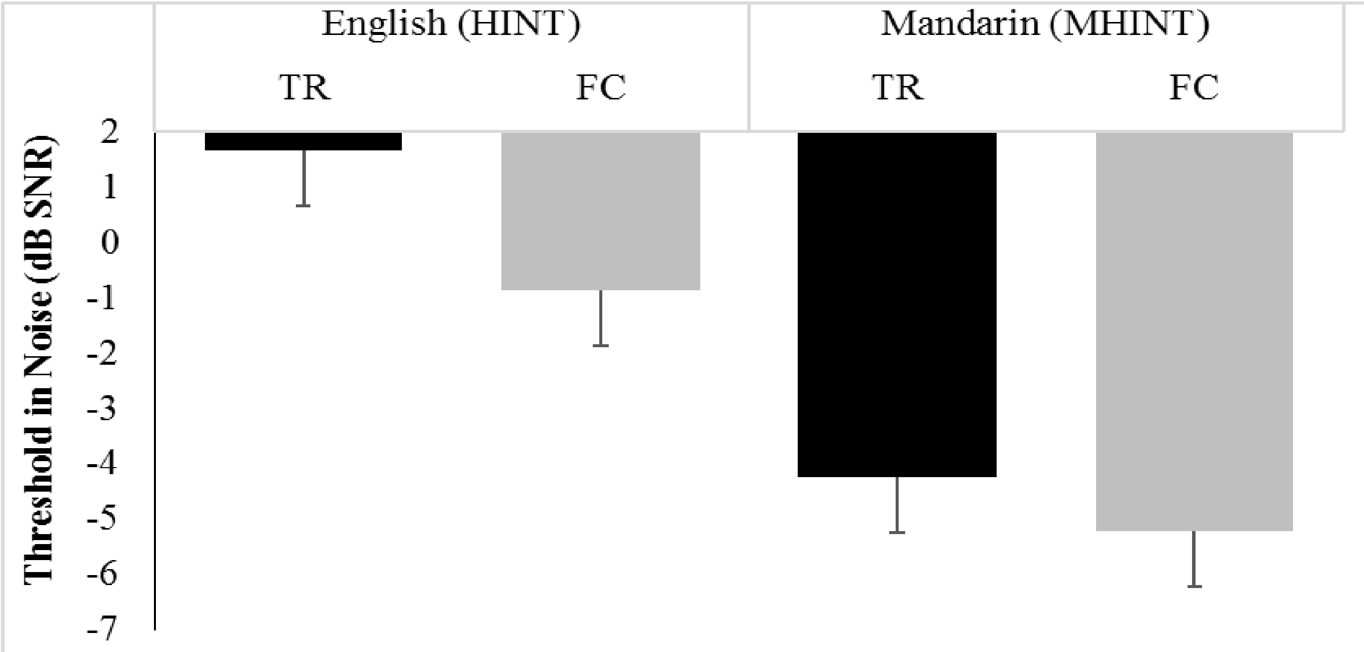

Figure 3. Average speech-in-noise thresholds with vertical bars representing one standard deviation. Note. HINT=Hearing in Noise Test. TR=Traditional. FC=Frequency Compression. M=Mandarin.

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.

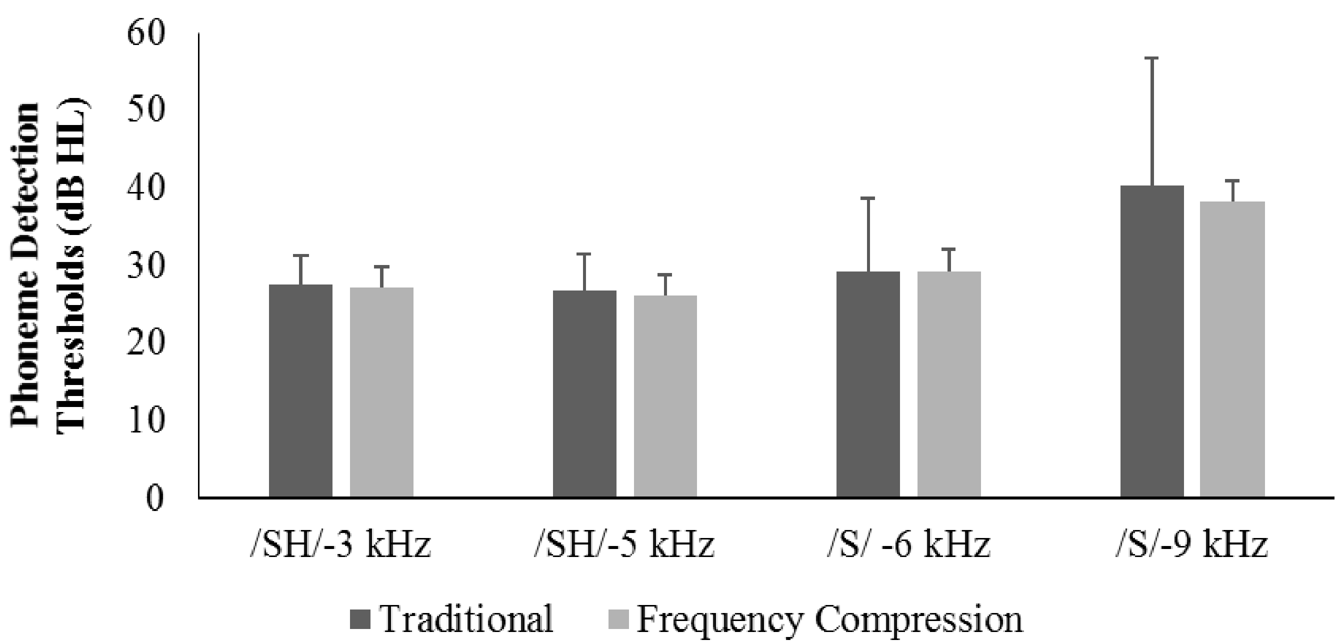

Figure 4. Average phoneme detection thresholds with vertical bars representing one standard deviation.

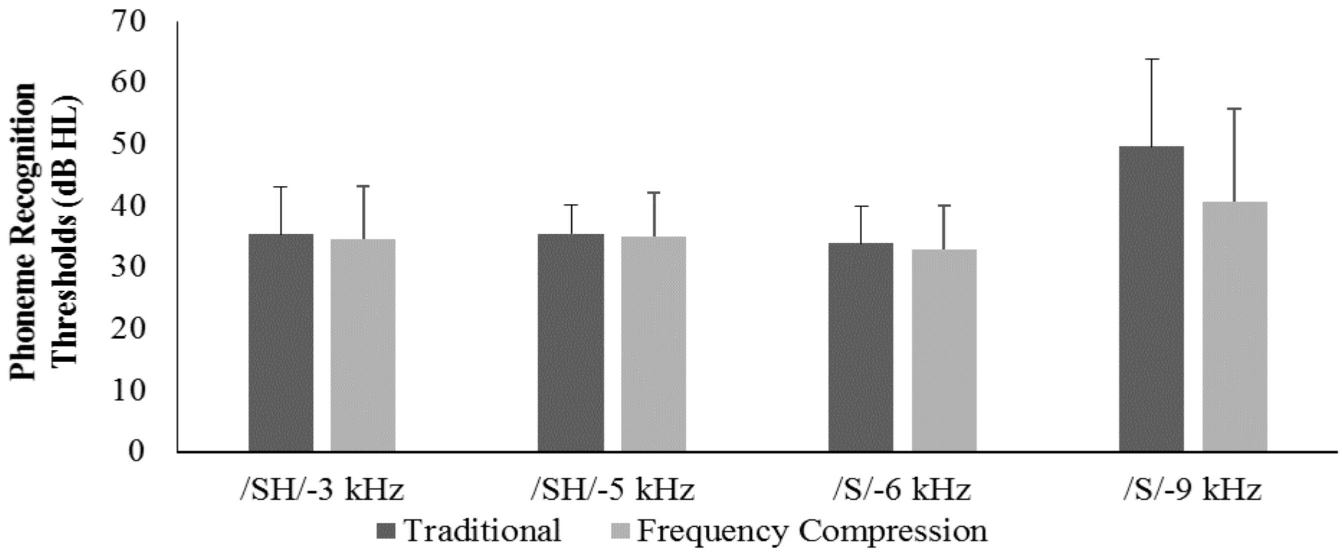

Figure 5. Average phoneme recognition thresholds with vertical bars representing one standard deviation.

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

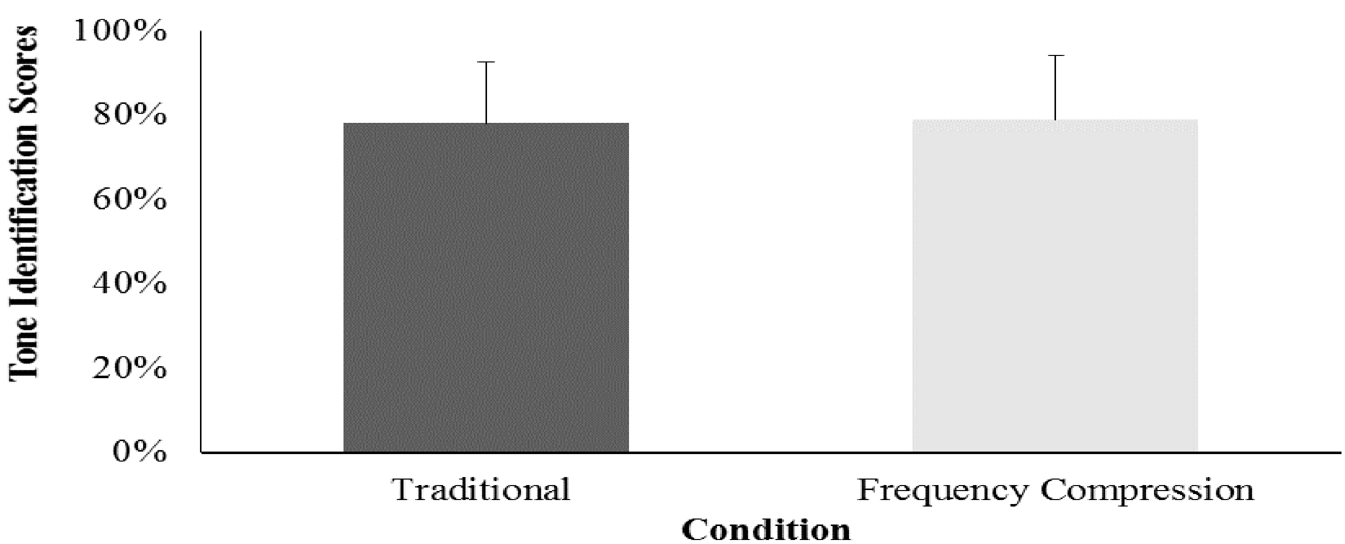

Figure 6. Average tone identification score with vertical bars representing one standard deviation.

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.

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Research Article

Computerized Rehabilitative Training in Older Adult Cochlear Implant users: A Feasibility Study

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Abstract

Purpose

Many older adult cochlear implant (CI) users struggle with speech recognition, suggesting a need for focused rehabilitation. Computerized "bottom-up" auditory training programs have demonstrated some efficacy, but "top-down" linguistic or neurocognitive training may be beneficial for some persons. Sixteen experienced older adult CI users were assessed for sentence recognition in quiet and in noise, along with phonological sensitivity, working memory, and CI-related quality of life (QOL). Twelve participants completed ten sessions of computerized auditory, working memory, or phonological training, with four participants per group, along with four controls. Broad variability was demonstrated among participants on changes in speech recognition, phonological skills, working memory, and QOL. This study confirmed the feasibility of a trial of computerized rehabilitative training for older adult CI users, but limitations of this approach are discussed.

Key Words: Auditory training; Cochlear implants; Cognition; Linguistic skills; Sensorineural hearing loss; Speech perception

Introduction

Cochlear implants (CIs) provide speech recognition benefits for many adults with acquired hearing loss. However, not all patients derive equal benefit, and 10 to 50% of adult CI users experience "poor" outcomes (Lenarz et al., 2012). For example, 35 to 50% of CI users cannot make use of the telephone (Rumeau et al., 2015), and 13% of adult CI users score less than 10% correct words in sentences in quiet (Lenarz et al., 2012). Even for those patients who do ultimately perform well with their devices, it may take greater than two years to reach a plateau in performance (Herzog et al., 2003; Lenarz et al., 2012), suggesting a prolonged period of central nervous system adaptation to the degraded input delivered by the CI. These findings together suggest an important role for aural rehabilitation following cochlear implantation, and this rehabilitation may be particularly important for poor performers.

To date, a variety of aural rehabilitation strategies have been developed, but a standardized approach for adult CI patients does not exist. Moreover, individualized one-on-one or group therapy with a trained Audiologist or Speech-Language Pathologist is rare in the United States, in part because it is rarely reimbursed by insurance providers (Sweetow & Palmer, 2005; Sweetow & Sabes, 2007). As a result, patients often turn to computer-based auditory training, which has shown inconsistent efficacy (Humes et al., 2009; Stacey & Summerfield, 2008; Stacey et al., 2010). These computer training programs generally provide what can be described as either "bottom-up" or "analytic" training, meaning the approach focuses on targeted training of recognition of individual perceptual units of speech, through repetition and feedback (Fu & Galvin, 2011; Henshaw & Ferguson, 2013;

Miller et al., 2008; Stacey et al., 2010; Wright & Zhang, 2009). In CI users, much of this work has been done by Fu and Galvin (2007; 2011), using one of several iterations of auditory training software (currently entitled Angel Sound™), focused on phoneme, digit, word, or sentence recognition. However, such training approaches do not always result in benefits, nor do they necessarily generalize to untrained speech materials. Moreover, previous training studies in adult CI users have not necessarily focused on older adults; for example, the 2007 training study by Fu & Galvin enrolled 10 adult CI users between the ages of 25 and 60, with mean age of only 42.4 years. Furthermore, older CI users likely experience aging-related declines that could impact their ability to understand degraded speech, through both deficits in auditory temporal and spectral processing (Fitzgibbons & Gordon-Salant,1994; Nambi et al., 2016) and cognitive processing (Salthouse, 1996). In particular, relevant aging-related declines in working memory capacity, inhibitory control, and processing speed may impact speech recognition in older adults (Tun et al., 2012; Wingfield & Grossman, 2006), and specifically in those with CIs (Moberly, Houston, & Castellanos, 2016).

There is some evidence that "top-down" or "synthetic" training may benefit patients with hearing loss (Chisholm & Arnold, 2012; Dubno, 2013; Sweetow & Palmer, 2005), though results are not entirely consistent (Wayne et al., 2016). These top-down approaches may actually be more effective than bottom-up training for older adults, at least for those with milder degrees of hearing loss (Rubinstein & Boothroyd,1987; Walden et al., 1981). Top-down approaches focus on training the patient to derive meaning from the speech input, and can include encouraging the listener to use context, linguistic skills, and neurocognitive functions to make sense of the signal. To our knowledge, there are only two published studies that have examined the use of more top-down computerized training strategies in CI users, focused on improving working memory and/or phonological skills, with both studies conducted in pediatric populations. Kronenberger and colleagues (2011) investigated the use of a working memory (WM) computer training program (Cogmed®) in nine prelingually deaf CI users between the ages of 7 and 15 years. As a group, the children demonstrated significant improvements on measures of verbal and nonverbal WM, as well as sentence repetition skills. Ingvalson, Young, and Wong (2014) took a similar approach in 10 pediatric CI users, ages four to seven years, except that the program was focused on training phonological skills along with auditory WM (Earobics®); the authors of that study also included nine control participants. Gains in expressive and composite language scores, including speech recognition, were found for children who underwent training, while no gains were identified for control participants. On the other hand, a study of adults with and without hearing loss failed to demonstrate benefits of WM training using Cogmed® on speech recognition in noise performance (Wayne et al., 2016). Nonetheless, findings in pediatric CI users suggest the potential for "top-down" training methods to improve outcomes in older adults with CIs.

In addition to a lack of studies examining top-down training approaches for adult CI users, to our knowledge, no studies have sought to investigate why some patients experience benefits from training while others do not. It is unclear whether particular linguistic and/or neurocognitive skills predict better gains in speech recognition performance as an effect of training; moreover, it is unclear if training itself can improve those linguistic and neurocognitive skills.

The purpose of this study was to determine the feasibility of an at-home computerized training study in older postlingually deaf adults with CIs, and to collect data examining speech recognition in quiet and in noise before and after training, along with phonological sensitivity and WM. Sixteen postlingually deaf adults with CIs were assigned to one of four groups: (1) Auditory training; (2) Working memory training; (3) Phonological training; or (4) No training (control). Goals were to assess the willingness of adult CI users to participate in a training study and to undergo repeat testing. Additionally the compliance of older participants to complete each of the training programs, and subjective perspectives on the three different training programs was also evaluated.

Materials and Methods

Participants

Sixteen adult CI users were consented to participate in this study. All had greater than one year of CI experience, were between the ages of 56 and 82 years (mean 68.4, SD 8.1), and were recruited from patients in the Otolaryngology department at The Ohio State University. Participants had varying etiologies of hearing loss and ages at implantation, but all users experienced a progressive decline in their hearing during adulthood. Age at implantation was between the ages of 48 and 76 (mean 63.6, SD 8.7), and duration of CI use was between 1 and 12 years (mean 4.8, SD 2.7).

A validated cognitive screening test, the Mini-Mental State Examination (MMSE), was used to rule out dementia or mild cognitive impairment (defined as a T score less than 29) prior to baseline testing (Folstein & Folstein, 1975). No participant demonstrated evidence of cognitive impairment. Participants were also assessed for basic word-reading ability, using the Word Reading subtest of the Wide Range Achievement Test, fourth edition (WRAT) (Wilkinson & Robertson, 2006), as a metric of general language proficiency; all participants demonstrated a standard score of ≥ 83, which is just below one SD below the normative mean. Demographic and audiologic data for the individual CI users are shown

Table 1. Participant demographics.

Participant	Training Group	Gender	Age (years)	Implantation Age (years)	Side of Implant	Better ear PTA (dB HL)	MMSE (T score)	WRAT (Standard Score)
1	Control	M	66	61	B	120.0	50	120
2	Control	M	69	65	R	78.8	30	99
3	Control	F	68	56	L	82.5	36	92
4	Control	M	82	76	R	98.8	61	114
5	Working Memory	M	79	76	R	88.8	63	107
6	Working Memory	M	78	74	B	115.0	38	94
7	Working Memory	M	68	62	R	82.5	50	90
8	Working Memory	F	72	66	L	120.0	50	83
9	Auditory	F	56	48	R	70.0	57	92
10	Auditory	M	58	57	B	112.5	57	122
11	Auditory	M	60	54	B	120.0	42	95
12	Auditory	F	59	56	R	115.0	59	90
13	Phonological	F	66	62	L	120.0	50	120
14	Phonological	F	62	59	L	108.8	35	92
15	Phonological	M	77	72	L	71.3	56	104
16	Phonological	M	75	74	R	87.5	63	111

Notes: PTA: pure-tone average; HL: hearing level; B: Bilateral; R: Right; L: Left; MMSE: Mini Mental State Examination; WRAT: Wide Range Achievement Test

in Table 1. All participants demonstrated better than 20/30 corrected vision as screened using a near-vision testing card. Participants were compensated $15 per hour of testing and training.

Equipment

All tests were performed in a soundproof booth or a sound-treated testing room. Participants were tested while using their usual devices (one CI, two CIs, or CI plus contralateral hearing aid), and devices were checked at the beginning of testing by having the tester confirm sound detection by the participant through each device.

Stimuli and Stimuli-specific Procedures

Speech Recognition Measures

Recognition was tested for several types of speech materials, with each word or sentence presented, and the participant was asked to repeat what was heard. All materials were presented at 68 dB SPL over a loudspeaker positioned one meter from the participant at zero degrees azimuth. Dependent measures were percent correct words. Because testing sessions were completed approximately one month apart, the researchers believed that procedural learning effects were unlikely to occur. Therefore, the same speech recognition materials were used at both testing sessions. Participant responses were audio- and video-recorded and scored later by two trained research assistants. These two research assistants double-scored 25% of responses independently to ensure inter-rater reliability, which was >95% for all tasks that required later scoring.

Sentence recognition in quiet. Two measures of recognition of words in sentences in quiet were included: (1) long, complex, and semantically meaningful sentences taken from the IEEE corpus (IEEE, 1969) (“Standard” sentences), such as “The wharf could be seen from the opposite shore”; and (2) Perceptually Robust English Sentence Test Open-set (PRESTO) sentences (Gilbert, Tamati, & Pisoni, 2013), which are also complex and high-variability sentences, such as “Our successors will have an easier task”; each sentence was recorded by a different talker to introduce gender and dialect variability. For each sentence type, listeners were presented with 30 sentences.

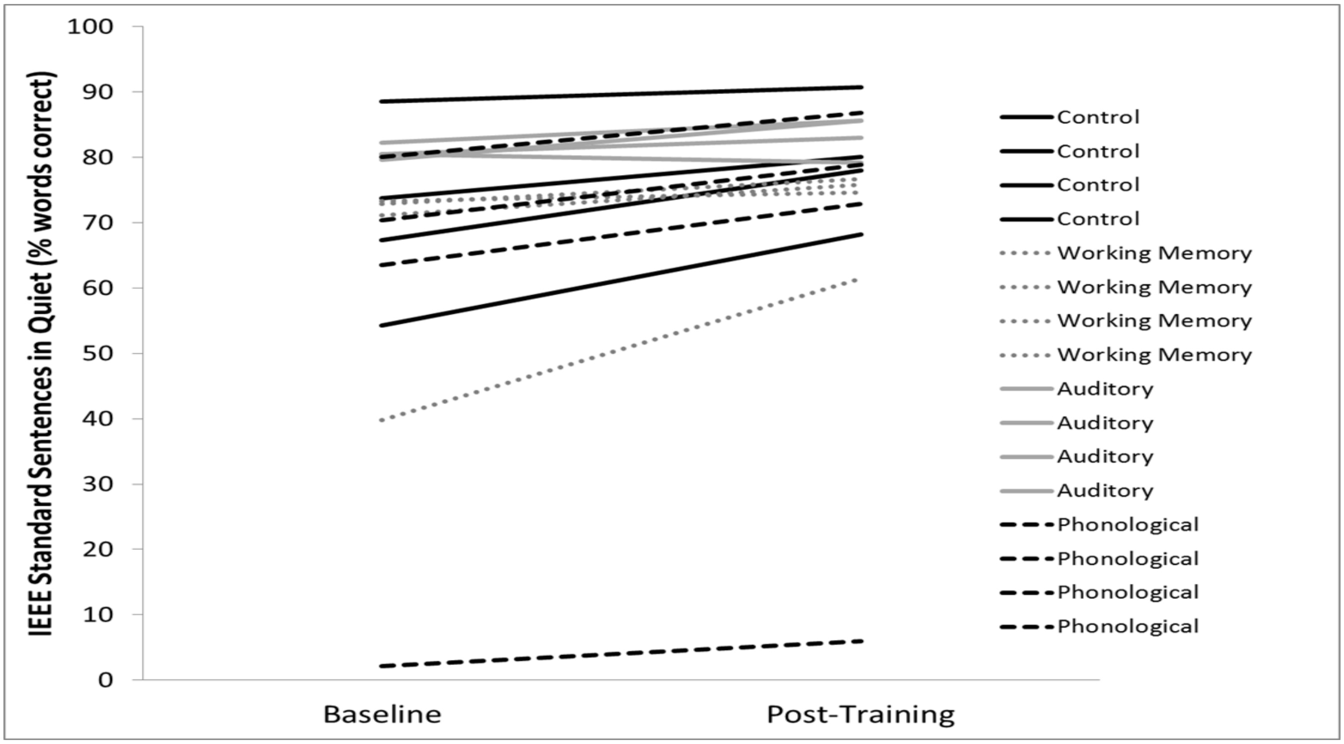

Figure 1. Individual participant scores for each group (control, working memory training, auditory training, and phonological training) on IEEE Standard sentence recognition in quiet at baseline (pre-training) and post-training.

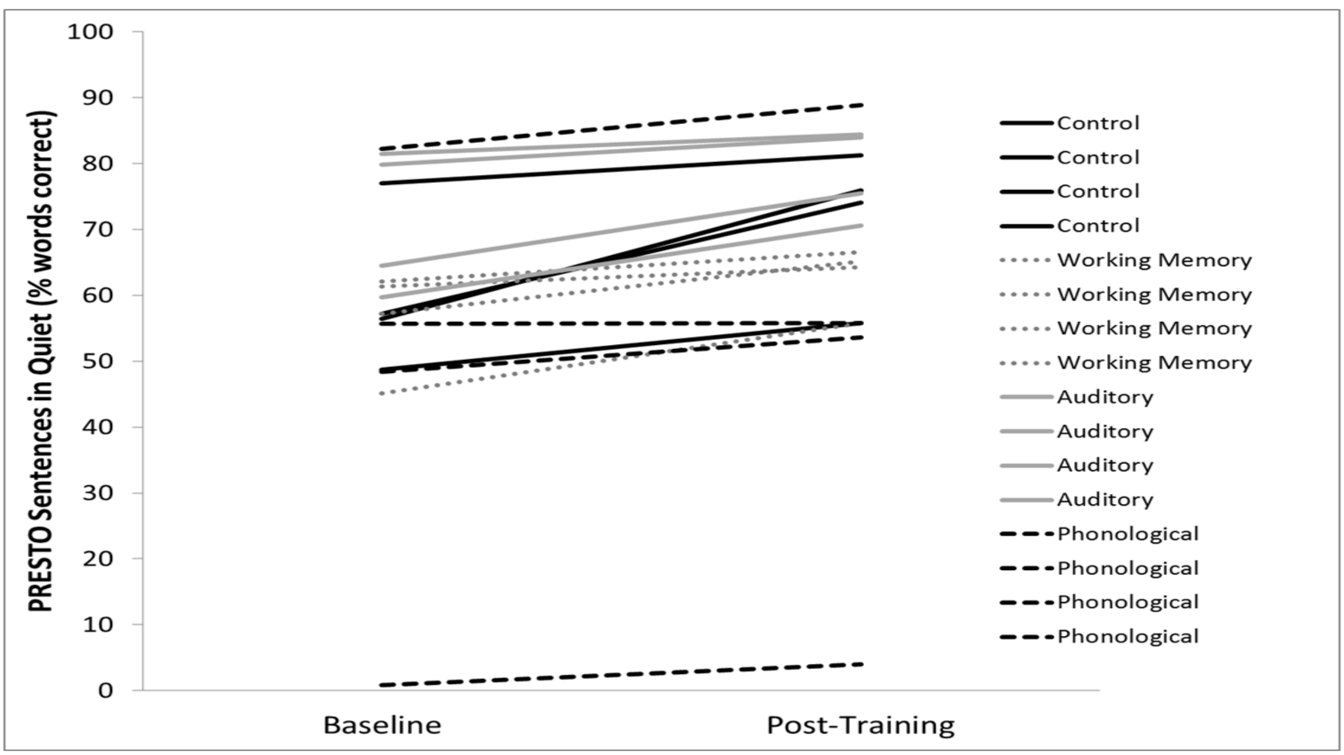

Figure 2. Individual participant scores for each group (control, working memory training, auditory training, and phonological training) on PRESTO sentence recognition in quiet at baseline (pre-training) and post-training.

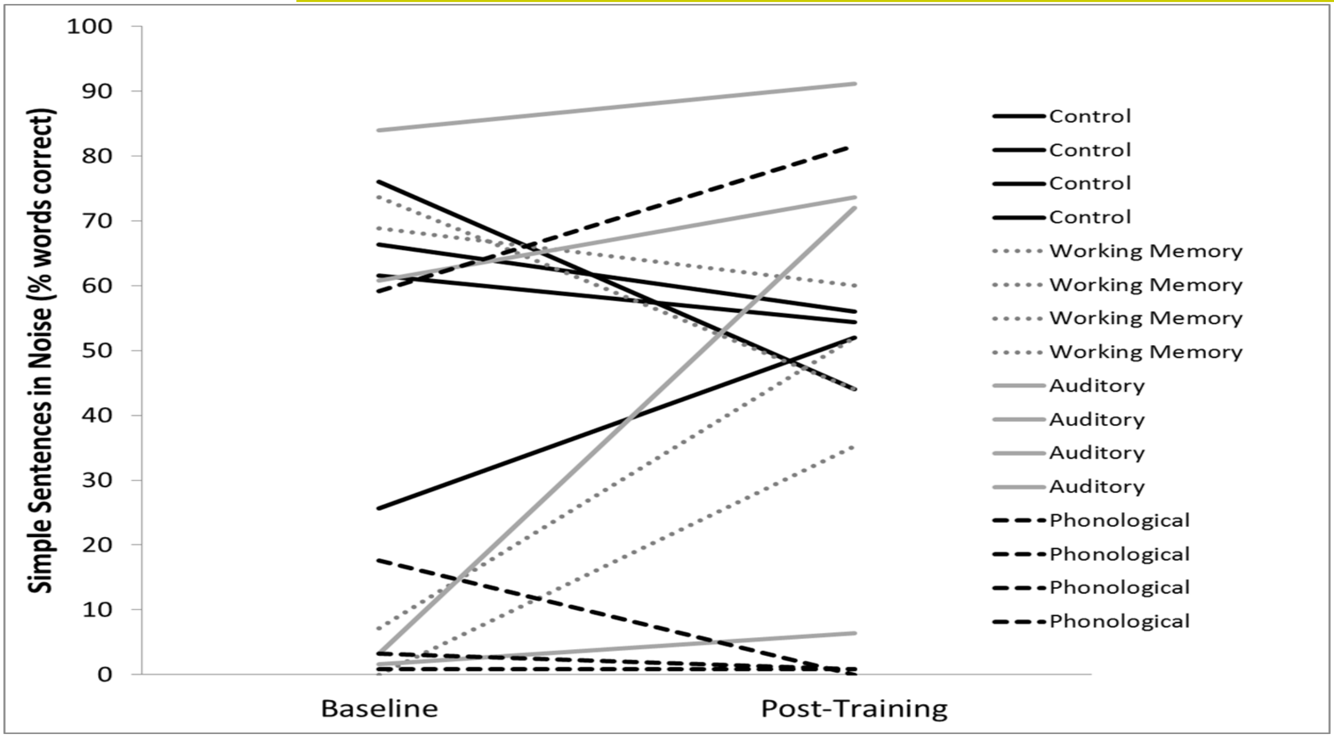

Figure 3. Individual participant scores for each group (control, working memory training, auditory training, and phonological training) on simple sentence recognition in speech-shaped noise at baseline (pre-training) and post-training.

Sentence recognition in noise. One measure of sentence recognition in noise was included. These were short, meaningful, five-word recorded sentences that were semantically predictable and syntactically correct, and followed a subject-predicate structure (e.g., "Flowers grow in the garden"); most of these sentences originated from the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994), and this modified set was originally used by Nittrouer and Lowenstein (2014). Participants were tested in speech-shaped noise at + three dB SNR.

Phonological Sensitivity Measures

Two measures of phonological sensitivity were collected, and have been used previously in adult CI users (Moberly, Lowenstein, & Nittrouer, 2016; Moberly, Harris, Boyce, & Nittrouer, in press). These tasks consisted of a Final Consonant Choice (FCC) task and a Nonword Repetition task. Both tasks were administered using an audiovisual format, in which the participant saw a talker's face on a computer monitor and heard the talker over the speaker. This was done to maximize participants' ability to recognize the stimuli. By maximizing stimulus recognition, scores on these phonemic awareness tasks would provide a more explicit assessment of participants' phonemic sensitivity (i.e., their long-term phonemic representations), rather than simply auditory phoneme recognition. In the FCC task, participants were presented with a target word, which they were asked to repeat correctly. They were then given three word choices, and they had to select which of the three words ended with the same sound as the target word. Practice with feedback was provided before testing. During testing, the task was discontinued when a participant responded incorrectly to six consecutive items. All remaining trials during that test were scored as incorrect in those cases. If the participant was unable to repeat a target word correctly after three attempts, that item was skipped and was excluded from analyses (counted as neither correct nor incorrect). The percentages of correct answers were used as the measures of phonological sensitivity during analyses.

The second task of phonological sensitivity was a Nonword Repetition task. Forty non-words between one and four syllables in length, developed by Gathercole and Baddeley (1996) were video- and audio-recorded by a male talker. Equal stress was placed on all syllables for all stimuli, and fundamental frequency was kept consistent and flat. Stimulus amplitude was constant. During the task, participants saw and heard the talker saying each non-word, and they were asked to repeat each non-word immediately. Four non-words were presented at each syllable length. Participant responses were recorded and scored later by two trained research assistants, as described above. For this task, phonemes were scored as wrong if they were omitted or if substitutions were used. Distortions were not scored as wrong. Scores of total percent correct phonemes across all syllable-string lengths were used in analyses.

Working Memory Measures

Two measures of WM were collected, one for auditory verbal WM, and the other for visual verbal WM. The auditory verbal WM task was a task of serial recall of monosyllabic, nonrhyming words, which has been used previously in adult CI users (Moberly et al., in press) and was developed by Nittrouer and Lowenstein (2014). Stimuli consisted of a set of six nonrhyming noun words. The nouns used were ball, coat, dog, ham, pack, and rake. All words were spoken and recorded by a male talker. Prior to testing, the participant saw a series of six blue squares on a computer screen and was required to tap the squares in order from left to right as quickly as possible. Five trials were completed, and average time across those trials (the calibration time) was used to normalize response times to test items. Participants were familiarized with the words to be used before testing by seeing the pictures at the top of the monitor and hearing each word presented by itself. The participant needed to tap the picture representing the word heard to indicate that the association was made. This procedure was done prior to and subsequent to testing as a way of verifying that the participant recognized the words. During testing, words were presented at a rate of one per second without the pictures being shown; following presentation of the six words, all the pictures appeared at once (randomly positioned). The participant was instructed to tap the pictures in the order heard, again as quickly as possible. Ten trials of each condition were included. Response accuracy was used as the dependent measure.

The visual verbal WM task was a computerized digit span task, based on the original auditory version from the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV-I, Wechsler, 2003). Visual stimuli were used to eliminate the effects of audibility on performance. Sequences of digits were visually presented on a computer screen, one at a time, and participants were asked to reproduce the lists of digits in correct serial order. Total number of correct digits in correct serial order was used in analyses.

Quality of Life Measure

Nijmegen Cochlear Implant Questionnaire (NCIQ). Details of this measure can be found in the report by Hinderink and colleagues (2000). The NCIQ was designed for CI users, and it encompasses hearing and speech, psychological, and social domains. Three subdomain scores were used in analyses (Physical, Psychological, and Social), with higher scores representing better QOL. Questionnaires were completed by participants at home by self-administration with no time limit.

Table 2. participant scores on linguistic/cognitive tasks and quality of life at baseline (pre-training) and post-training.

		Baseline (Pre-Training)					**Post-Training**				
		Phonological Skills		Working Memory		QOL	Phonological Skills		Working Memory		QOL
Participant	Training Group	FCC (% CI)	NWR (% CP)	SRW (TCI)	VDS (TCI)	NCIQ (SS)	FCC (% CI)	NWR (% CP)	SRW (TCI)	VDS (TCI)	NCIQ (SS)
1	Control	85.4	81.3	45	77	227.3	83.3	73.0	42	97	231.3
2	Control	79.2	84.4	33	76	242.7	87.5	78.0	41	58	238.6
3	Control	47.9	76.0	27	43	256.2	58.3	77.0	31	24	272.7
4	Control	75.0	74.0	41	44	167.1	70.8	72.0	41	49	166.9
5	WM	20.8	69.8	21	30	161.8	41.7	72.0	28	21	174.5
6	WM	52.1	70.8	28	32	181.8	58.3	66.0	31	35	200.2
7	WM	47.9	72.9	37	34	275.1	52.1	61.0	30	22	250.7
8	WM	45.8	71.0	20	32	246.7	68.8	78.0	28	31	249.6
9	Auditory	85.4	74.0	46	46	181.9	85.4	80.0	31	46	-
10	Auditory	91.7	87.5	33	76	174.0	91.7	92.0	37	18	189.8
11	Auditory	87.5	81.0	44	44	141.3	79.2	80.0	46	59	145.4
12	Auditory	79.2	83.0	34	36	159.4	87.5	71.0	54	31	-
13	Phonological	89.6	76.0	42	63	229.6	89.6	77.0	33	79	247.9
14	Phonological	79.2	67.7	40	58	172.5	79.2	76.0	36	50	172.9
15	Phonological	70.8	48.0	22	24	156.5	-	73.0	-	33	174.6
16	Phonological	10.4	67.0	35	38	159.7	14.6	58.0	25	45	161.8

Notes: QOL: Quality of Life Measures; FCC: Final Consonant Choice; NWR: Non-word Repetition; SRW: Serial Recall of Words; VDS: Visual Digit Span; NCIQ: Nijmegen Cochlear Implant Questionnaire. %CI: % correct items; %CP; % correct phonemes; TCI: total correct items; SS: sum score.

Open-ended Questionnaires Regarding Training Programs

Participants completed a daily log recording when they completed their training session. They also completed an open-ended questionnaire at the post-training testing session that was developed and used to assess participant perspectives of training regarding feasibility and subjective experiences. Questions were asked about what participants did and did not like about the training program, barriers to training experienced, appropriateness of length of training sessions, training program features that seemed most and least beneficial, and willingness to complete more than two weeks of training.

Table 3. Participant subjective responses to questionnaires about training programs.

QUESTION	Auditory Training	Phonological Training	Working Memory Training
1. What did you like about the training program?	• It helped me to work to understand words better than I had. • It was hard and intense! • Feedback was good. Different constructs offered different learning. • Assistants were very accommodating to my schedule and always so patient and willing to help in any way.	• Challenging. Repeat button. • Variety of exercises. Progressive lessons. I liked the way programs flashed a red light for error and green for correct. Positive feedback was also nice. I liked the way the program started simpler and evolved into more difficult. • Even four years as a CI user, Rhyme-Time was challenging with loud background noise. • I really believe in strategies that promote success for a period of time, which I think many of these programs did in the beginning.	• It forces you to concentrate on remembering many things, sounds, moving objects, and organizing some things. • Made it convenient for home training set at my own pace. • Awareness.
2. What didn't you like about the training program?	• The noise in the background of some modules was really hard to hear past. Sometimes it sounded like the woman was saying the same thing three to four times in a row. • Equipment malfunction (keyboard). Positive feedback was time-consuming. Lingering on it (repetitions of correct and incorrect answers) was annoying. • These programs require intense focus and more than a second or two was annoying. After hearing the same sentences several times, I could figure out words I did not actually hear. • It handles misspellings as mishearing. The concatenated sentences has a bug that can place a word in the wrong column.	• It has verbal instructions for hearing impaired, and clarity of speech is poor. • Overly noisy and time was wasted. Lacked reinforcement. I would benefit from having the words/sounds printed on the screen after making the choice. • I did not like all the extra noisy sound effects between tasks. Those types of noises can be almost painful to hear. I would keep the training level quieter between tasks. I think trying to sound out all the various sounds in a one syllable word such as toy or dog is somewhat counter-productive. • If developing tasks with a noisy background, I think a noisy restaurant crown sound (real-life scenario) or whooshing air (sound of tires on pavement) might be better.	• When you did not correctly identify the answer, it did not show you what your mistake was. • The moving objects could be frustrating at times, especially the clock grid. • Made me feel stupid! The voice on the letters was tricky. • Tedious.
3. Do you feel as though your listening effort has improved following completion of the 2-week training program?	• Yes. • Maybe in the short term. Improvements probably won't last long. • Yes. • Yes.	• Don't know. • Yes, but also an awareness of sounds I am not hearing or differentiating. • As a four year CI veteran, I do not think this program made any difference at my stage of CI use.	• I have not noticed any differences, but maybe people around me can see an improvement. • Hard for me to say. • No.

Table 3 (Cont.)

4. Were there any barriers to participating in the training program?	• Just finding the time. I usually did the training at night which unfortunately was when I was most tired. • Equipment malfunction, vertigo attack. • The time commitment was problematic. • Finding an un-interrupted block of an hour was often challenging. Also, when I changed levels, the module could take twice as long, particularly on those that have long training cycles.	• No. • The computer would freeze about halfway through each session. I had to shut the computer down and start over. Also, speaker had to be unplugged from laptop each session or it would not operate. • No, had quiet environment at home in which to practice and no issues with technology.	• Just be sure to pick a quiet area. Noise in the background can be a problem. • No. • None for me. • No.
5. Were training sessions a good length, too short, or too long?	• Since they normally lasted 45-50 minutes, I thought they were a little lengthy. • They were a good length. • When I was scoring well, they were fine. When I wasn't, and the mistake training loops were wrong, it was taxing. • The day-to-day sessions were a good length for me.	• Length was fine. • Doing one activity per "game" wasted time. • Would be better to do several activities of each game. Too much "filler." • Good length for many who work.	• I had no problems with the length. • Need enough time to understand how to use the program and the computer. • I felt that they were a tad too long as some of them were more taxing toward the end. If I was doing well, it was too short. If I was doing bad, it was way too long. • Good length.
6. What particular features of training seemed the most beneficial?	• All of them had some benefit. • Forced me to make a regular time to test and focus. • A quick correction loop is helpful. • The sessions with light background noise helped me to concentrate more on what was being said.	• Don't know if one was better than the others. • RhymeTime was the most difficult, had to guess a lot. • Being able to repeat and relisten. • To obtain and see results that one could share with audiologist would be nice.	• None. • My mind likes to "travel" so this helped me in trying to stay focused to a degree. • Vocal tasks.
7. Were there any particular features of training that did not seem helpful?	• No. • No. • I was frustrated when misspellings or phonetically identical words were treated as wrong. • Some parts had so much background noise I could not make out any words.	• RhymeTime because of the poor quality of speech. • Would benefit by putting printed words on the screen as the word was repeated. • Extra loud noises between tasks and programs were more than annoying, could frighten beginning CI user.	• Rotating Drills. • Reverse Numbers.

Table 3 (Cont.)

8. Were there any particular features of training that were too easy or too hard?	• For the noise module where you had to type back the sentences, you had to spell everything exactly right. Also when you got it incorrect it repeated everything too many times. • Speech babble was hard, but it was most like the challenges I face daily. • The sections with a lot of noise were too difficult so I guessed.	• No. • The introduction of background noise was unexpected, so introduce noise soft to loud. • RhymeTime with loud siren-like noise was annoying, and task was too hard.	• Certain problems where there were moving or spinning objects seemed to cause me more vertigo. • The easiest was repeating letters. The moving circles were the hardest. • Numbers in reverse order was too hard.
9. Is this training program something you would be willing to do for longer than 2 weeks?	• Maybe off and on but for me it was hard to get in 10 days with my work and life schedule. • Not sure. • Absolutely, I would like guidance on the modules that are most effective. • If it did not have to be daily then yes. If it is necessary to do the sessions daily then two weeks was fine.	• Yes, if the quality was better. • Yes, I actually wanted to complete the activities. • Yes, I would have used this program until I was getting 90% or better on most of the tasks.	• This program seems to get very repetitive after six to seven days. • Yes. • Yes. • Maybe.
10. Do you feel as though more training would further improve your listening skills with your cochlear implant (s)?	• Yes. • Not sure. • Absolutely. • Perhaps but on the parts with heavy noise it may help that when you replay the sentence that it becomes a little more clear.	• Yes. • Couldn't hurt. • At this point, I'm not sure.	• Maybe some other programs might help. • Possibly. • Cannot say. • Yes.
11. Additional comments?	• On typing sentences, make it easier to correct instead of having to backspace and retype. On concatenated sentences, don't have it repeat itself so many times. • Clearer feedback. • A few more seconds to read the words when listening for sounds. • There should be a "none of the above" or "best guess" button on babble to distinguish random guessing from educated guessing.	• I would include a variety of voices - women, men, children. • A variety of background noises. • Rehab would be better with a hearing partner.	• Wish it would show the correct answer so I know where my mistakes are. • Working with the alphabet and numbers was helpful. • I tried to train at different times of day to see how I would do, also checked my blood sugar. The only thing I felt was that late afternoon was not good.

Auditory Training

Angel Sound™ is an online PC-based interactive auditory training program developed by TigerSpeech Technology, is distributed freely by the Emily Shannon Fu Foundation, and can be accessed at http://angelsound.tigerspeech.com/angelsound_about.html. In brief, this program consists of a variety of self-paced modules with different types of adaptive listening exercises, and it provides audio-visual feedback. eight tasks over approximately one hour: (1) "Everyday Sentences" from the Basic Module – In this task, the participant hears a sentence in quiet and chooses from four closed-set options. (2) "Everyday Sentences" from the Noise Module – In this task, the participant hears a sentence embedded in speech babble and is asked to identify a keyword from that sentence, selecting from four closed-set options. (3) "Sentences" from the Openset Module – In this task, the participant hears a sentence and is instructed to type the sentence heard. This task begins in quiet, then in speech babble at 10 dB SNR and at 0 dB SNR as the participant progresses. (4) "Concatenated Sentences" from the Openset Module – This task is similar to "Sentences," but the participant clicks on the words that make up the sentence from columns of words choices; training is done in quiet and in speech babble at 10 dB SNR and 0 dB SNR. (5) "Speech Test in Noise" from the Assess Module – In this task, the participant hears sentences in speech babble and identifies a key word from a closed set of six options. Additional details of these tasks can be found on the Angel SoundTM website.

Working Memory Training

The Cogmed® Working Memory Training program (Pearson, San Antonio, TX) is a video game-like program that consists of exercises requiring auditory, visuospatial, and audiovisual short-term and WM skills. These tasks use an adaptive algorithm to increase difficulty as performance improves. Participants completed approximately one hour per day, which consisted of the following eight exercises: (1) "Sort" – boxes with numbers light up on the screen in a sequential order, and the participant is asked to click on the boxes in the correct numerical order using the mouse. (2) "Cube" – squares lining the sides of a cube light up in a certain order, and the participant clicks on the squares in the same order they lit up. (3) "Hidden" – Numbers are presented auditorily, and the participant clicks on the numbers on the screen in the reverse order they were presented. (4) "Twist" – Circles forming a four by four square light up on the screen as the larger square rotates, and the participant clicks on the circles in the same order they lit up. (5) "Assembly" – Several letters are presented auditorily, and the participant clicks on the letters on the screen in the order they were heard. (6) "Chaos" – Several shapes on the screen are moving in random fashion. Shapes light up one at a time but continue to move, and the participant recreates the sequence by clicking on the shapes in the order they lit up. (7) "Rotating" – A large circle consisting of small circles along its circumference rotates, and the smaller circles light up one at a time. The participant clicks on the circles in the order they lit up. (8) "Numbers" – Numbers are presented auditorily, and the participants click on the numbers on the screen in the reverse order they were presented.

Phonological Training

Earobics® (Houghton-Mifflin, Evanston, IL) version one for adolescents and adults was used. Four tasks were completed over approximately one hour per day: (1) "Sound Check" – The participant hears a target phoneme and uses the mouse to click on the associated letter representing that phoneme if the sound was heard individually or in a monosyllabic word. With progressive completion, the participant is asked to indicate if the sound is heard at the beginning, middle, or end of a word. (2) "Get Rhythm" – The participant hears a sound a certain number of times and then is asked to click on an object displayed on the screen once for each time the given sound is heard, initially for each syllable heard in a word, and then later for each phoneme heard in a word. (3) "Connectivity" – The participant clicks on pictures of words heard. With progressive completion, the participant clicks on the picture of the word that the syllables or phonemes create. (4) "Rhyme Time" – The participant clicks on a word that does not rhyme with the other words shown and heard. With progress, the participant selects which word shown visually rhymes with a word presented auditorily.

General Procedures

All procedures were approved by The Ohio State University Institutional Review Board. Participants were tested at baseline on one day during a single session of approximately two hours. First, hearing thresholds and screening measures were obtained. Following these, the order of presentation of tasks was randomized across participants.

After baseline testing, participants were allocated to one of four groups: (1) Auditory training; (2) Working memory training; (3) Phonological training; or (4) Untrained control. Because the primary purpose of this study was simply to evaluate whether older CI users would remain compliant with a training program, and explore their overall experiences with such home training options, patients were allocated to the four groups non-randomly. That is, we attempted to assign patients with the poorest WM to the WM training group, and those with poor phonological sensitivity to phonological training.

Each participant who received training was asked to complete 10 training sessions, each approximately one hour in duration, over two weeks. Except for the first session, training was completed at home using a laptop computer, mouse, and speaker provided by our lab. Each group underwent a pre-training workshop of approximately three hours prior to beginning training at home. This workshop consisted of a lesson with hands-on practice to set up the laptop, connect the mouse and speaker, test the sound, and log into the respective software program. Following this lesson and hands-on practice with the computer hardware, participants split up and completed their first one hour training session with the appropriate software program in separate rooms in our laboratory. This way, members of the lab were available to help troubleshoot the first training session for each participant. Several participants brought family members to assist them in setting up the training hardware at home. Participants and family members were able to email, text, or call laboratory research assistants as needed from home during the two week training period. They were asked to complete a daily log of training activities to verify completion of training. Objective computer reports were generated for participants who completed Auditory and Working Memory training, but these reports were not provided by the software for those who completed Phonological training.

Participants adjusted the speaker volume to their most comfortable listening level for training, and they wore their usual devices (one CI, two CIs, or CI with contralateral hearing aid) during training.

Following the two week training period, participants came back to the laboratory for repeat testing of speech recognition, phonological sensitivity, and WM. Control participants completed repeat testing between four and six weeks following baseline testing.

Data Analyses

Because this feasibility study consisted of a small number of participants, data analyses that could reasonably be performed were limited. Group means and standard deviations for speech recognition, phonological, WM tasks, and QOL were computed. Responses to open-ended questionnaires were summarized.

Results

All 16 participants completed pre- and post-training assessments. All 12 participants assigned to training groups completed all 10 sessions of training; which was verified by review of participants' daily log of training at the end of the training period (all participants demonstrated training for 10 sessions) and confirmed by computer output reports for those who completed Auditory and Working Memory training, as noted above. For those who completed Phonological training, individual training logs supported training completion, but no objective method was available to confirm this. Individual speech recognition scores plotted in Figures 1 through 3 show that a large amount of inter-participant variability was demonstrated across all measures. Speech recognition scores among some participants showed improvements, while other participants demonstrated similar or worse performance post-training. Although group sizes were too small to perform statistical comparison, visual inspection of speech recognition plots did not reveal clear performance improvements for one group over other groups. Notably, for all three speech recognition tasks, some control participants demonstrated improved scores between the first and second testing sessions.

Table 2 shows pre- and post-training scores on phonological, working memory, and QOL measures. Again, group sizes were too small for statistical analysis, but visual inspection of the raw data again demonstrates variable changes among individual participants on these measures. Similar to the speech recognition measures, control participants showed improvements on some measures between the first and second testing sessions.

Subjective responses to open-ended questionnaires are shown in Table 3. Several general themes deserve consideration. Overall, participants enjoyed being actively involved through training and trying to improve their speech recognition. They found the computer-generated feedback during the exercises to be helpful, and a variety of exercises in each training program seemed beneficial. However, several barriers to training were apparent. First, some participants experienced equipment/software malfunctions. Second, some patients found particular aspects of feedback or exercises annoying or tedious. For example, one program incorporated extraneous sounds to try to encourage attention of the trainee; instead the CI users found these environmental sounds distracting or even unpleasant. Thus, there were some frustrations regarding applying training programs that were not specifically designed for individuals with hearing loss – both the Working Memory and Phonological training programs – to clinical populations of hearing-impaired patients. Third, some particular training modules were particularly frustrating to complete; one module required open-set responses to be typed by the patient, but the response had to be spelled perfectly correctly to be counted as correct. Finally, over half of the participants either doubted that ongoing training would be beneficial, or they stated that they would not be willing to continue training with their program beyond the two-week period.

Discussion

This study was conducted to evaluate the feasibility of using at-home computerized training programs for postlingually deaf adults with CIs, most of whom were over age 60 years, using three different types of training programs in a small group of experienced CI users. Although the small sample size included in this pilot study precluded statistical analyses, several findings are worthy of discussion.

First, this study demonstrated that CI users were able to set up the at-home computerized training hardware, and completed all 10 sessions of at-home training. Compliance was high in our group (100%) for completion of 10 training sessions, and compared favorably with reported compliance rates in other studies, which have been found to be as low as 30% and as high as 100% (Henshaw & Ferguson, 2013; Sweetow & Sabes, 2006; Sweetow & Sabes, 2010). Our high rate of compliance may have been encouraged by our use of daily training logs and software that automatically output reports of training sessions, at least for the Auditory and Working Memory training programs. Furthermore, participants were paid to complete this training which may have also increased compliance. It was apparent during the pre-training workshop for each training group, that this workshop facilitated preparation of participants to set up and complete the computerized training at home. For example, several participant comments related to the exchange of questions and answers with our research assistants in relation to hardware troubleshooting. Several participants also required some ongoing assistance from our research assistants and/or family members during their at-home training period, through email or texting, in order to complete the sessions. This observation suggests that although computerized training programs are widely available to adult CI users, use of these applications creates technical challenges for some older adults. Thus, clinicians recommending training programs for their clients should consider that some older patients will need personal technological assistance to complete training effectively.

A second major finding of this feasibility study was that, although patients generally enjoyed taking a more active role in trying to improve their speech recognition performance through training, there were a number of limitations to computerized training. In addition to requiring technical support for the hardware/software use, some participants experienced equipment and software malfunctions that impeded training. Also, several training modules were too difficult, too tedious, or frustrating to complete, especially those modules not designed specifically for the hearing-impaired. Lastly, many participants simply did not feel as though the training was useful. They commented that they would not likely continue their particular training program beyond two weeks if given the option, and they did not think ongoing training would be beneficial.

A third finding of this study was that performance of the control group/condition is of particular interest. While all groups were comprised of small numbers, CI users in both the training groups as well as some members in the control group demonstrated speech recognition gains and some improvements in QOL. It is unclear exactly why these improvements were observed; however, researchers could not control whether or not the participants in the control group did any training on their own. One alternative to a passive control group (as applied here) would be to include a separate active control group that performs a task for a similar amount of time as the training participants, but uses a task that is unlikely to provide any sort of training benefit (such as performing a very easy task of a similar nature to the training task, or performing a task that is completely unrelated). A problem with this approach, however, is that control participants may realize that their training tasks seem completely unrelated to the outcome of interest, or that their training exercises are too easy and tedious to be compliant with training. Another option is to perform multiple repeat baseline assessments of performance in the training group, which allows each participant to serve as his or her own control. The benefit of this single subject design approach is that it eliminates the need to assign participants to a group in which no actual effect is expected; a downside, though, is the greater possibility of procedural learning effects as a result of multiple repeat measures using the same tasks. Nonetheless, incorporation of a control group is essential in training studies, as evidenced by the performance improvements demonstrated by some of our control participants who did not undergo training.

This study clearly has several limitations. First and foremost, as a feasibility study, the sample was very small, and statistical analyses could not be performed to identify inter-group differences in training benefits between "bottom-up" and "top-down" training approaches. Second, patients were not randomly assigned to training groups; instead, they were assigned to training program based on their pre-training performance on measures of phonological skills and WM. For example, a participant with relatively poor phonological skills was assigned to the phonological training group. This was done by design to try to optimize participants' chances of benefitting from their assigned type of training and also to maximize participant enrollment for this feasibility study. Third, researchers and participants were not blinded to the group to which participants were assigned. In a future, larger-scale study of training, participants will need to be randomly assigned to control and training groups, and researchers (at least those performing the pre- and post-training testing) will need to be blinded to participant treatment group. Finally, test-retest improvements in outcome measures should be considered, particularly since some control participants demonstrated improvements between the first and second testing session. The same speech materials were used in the pre- and post-training assessments. Although these testing sessions generally took place approximately one month apart, it is possible that participants demonstrated list learning effects. A potential solution is to develop test lists that have been used in a control population and have demonstrated list equivalency, and/or to include a large control group in the main study for which test-retest learning effects can be assessed.

Although this study demonstrated the feasibility of implementing a computerized rehabilitative training study in older adult CI users, we are not convinced that the patient-driven computerized training approach should be applied broadly to older adults with CIs. Some participants needed support from family members or lab assistants for computer hardware/software issues. Some participants found training to be tedious, or aspects of the programs were annoying. Subjective comments demonstrated that by the end of two weeks of training, several participants probably would not have continued training if given the opportunity. Because of these limitations, our group is now exploring clinician-guided aural rehabilitation approaches to training for adult CI users to investigate the potential to optimize speech recognition outcomes. For example, CI patients are seen once a week for six to eight weeks by a speech-language pathologist to perform clinician-guided training exercises, using a combination of tasks like speech tracking, text following, sentence repetition with cueing, following verbal directions, and sentence completion using the surrounding context.

Finally, this feasibility study did not allow us to determine whether bottom-up or top-down training is more effective for older adults with CIs. The "bottom-up" and "top-down" training programs used in this study may hold potential for improving speech recognition performance, phonological skills, working memory, and QOL. A current study is comparing the effects of bottom-up versus top-down training, using clinician-guided aural rehabilitation approaches. In contrast, some authors have recommended the use of an "integrated auditory-cognitive" approach to training (Ferguson & Henshaw, 2015), where cognitive processes are targeted within speech training tasks, rather than by training cognition directly.

Conclusions

Adult CI users demonstrated successful completion of short at-home computerized training programs, including those who were elderly. However, significant limitations of computerized training approaches exist for this population. These specifically include hardware/software issues, the ongoing need for support from research assistants and/or family members, the tedious and sometimes frustrating nature of computerized training modules, and the perceived lack of benefit gained from some training exercises. Clinicians recommending training programs for older adult CI users should use discretion in selecting the type of training for any given patient.

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Research Article

Interactive Metronome: Research Review Related to Treating Auditory Processing Disorders in Children

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Abstract

Introduction

Interactive Metronome (IM) is a computer-based neurological assessment and treatment tool to improve processing abilities (McGrew, 2013).

Methods

A search of electronic databases, peer reviewed journals, and various clinical reports between 1995 and 2017 was conducted to review research literature and analyze the evidence available for using IM to treat auditory processing disorders (APD) in children.

Results

The literature suggests that IM improves auditory temporal processing, language comprehension, reading, and attention skills that are deficient in children with APD.

Conclusions

Further assessments of IM training is needed to support its use, as an effective rehabilitative treatment.

Introduction

Interactive Metronome® (IM) is a patented computer-based interactive version of a traditional music metronome (Cassily, 1996). Jim Cassily, an acoustics engineer, developed IM in the early 1990s. In 1994, he created a remote-control headset that presented metronome beats to help a child walk with a new prosthetic leg. Success led Cassily to apply IM to help children with learning and developmental disorders (McGrew, 2013). IM is a brain-training assessment and treatment tool used for pediatric and adult individuals to improve processing abilities that affect attention, motor planning, and sequencing.

The Interactive Metronome program consists of a software, a master control unit, a hand trigger, insole triggers, a tap mat, and headphones. The software includes a reference tone, guide sounds transmitted through headphones, visual guidance through the computer screen, graded sequential interactive neuro motor exercises, and the ability to record the speed of the patient's response. IM provides rhythm and timing training by presenting an auditory tone in the form of metronome beats through the headphones. The listener matches the timing of the beats with handclaps or foot taps, and obtains feedback from a computerized hand and foot sensor as shown in Figure 1. The listener learns to match the rhythm of the beat in a synchronous manner, which requires an integration of auditory perception of rhythm with the motor task (such as clapping hands). The training provides the listener with auditory and visual feedback that indicates the extent to which the beat of the metronome was matching to the rhythm of the motor task. The motor responses are classified as either too quick (before the tone

Fig. 1. The IM equipment consists of a software, a master control unit, a hand trigger, insole triggers, a tap mat, and headphones (Reproduced with permission from Interactive Metronome®)

was heard), too slow (longer than expected after hearing the tone), or on target (within a specified millisecond time limit after hearing the tone). It has been hypothesized that this feedback improves temporal processing and neural efficiency, leading to improvements in auditory, sensory, motor, and cognitive functions (McGrew, 2013). Because the improvements are based on auditory processing of the rhythmic beats, it is believed that IM training improves auditory processing abilities, especially auditory temporal processing.

Audiologists, occupational therapists, physical therapists, speech-language pathologists, psychologists, and educators have described IM as a potentially successful training technique (Alpiner, 2006; Etra, 2004; Shaffer et al., 2001). Researchers claim that IM improves rhythm, temporal processing, and motor coordination, as well as auditory processing and language comprehension abilities. The purpose of this article is to review the evidence available regarding IM, and to determine whether it is an efficacious and effective treatment for children with auditory processing deficits referred to audiologists, speech language pathologists, and occupational therapists.

Method of Research Review

The literature search included research and non-research based articles published between 1995 and 2017. The resources included electronic databases such as Education Resources Information Center (ERIC), MEDLINE, Cumulative Index to Nursing, and Allied Health Literature (CINAHL), Cochrane Database of Systematic Reviews, and eBook Clinical Collection (EBSCOhost). Key words used to search the literature included the following terms: "Occupational Therapy", "Audiology", "Auditory Processing", "Speech Language Pathology", and "Interactive Metronome". Recently published articles in peer-reviewed journals, including the Journal of Neurological Sciences, Neuropsychologia, American Journal of Occupational Therapy, Journal of Speech Language and Hearing Research, Psychology in Schools, Trends in Cognitive Sciences, Journal of Music Therapy, American Journal of Psychiatry, Annual Review of Neuroscience, International Journal on Disability and Human Development, and various other national and international journals were reviewed. Reported case studies, and clinician reports from various institutes around the United States were gathered and evaluated. Also examined were materials presented at professional conferences by one of the co-authors of this paper. A graduate assistant conducted the searches, and generated 118 relevant citations based on the title and/or abstract. The first two authors independently reviewed the abstracts of these articles and excluded those that were irrelevant. They also reviewed the reference lists of the published articles to identify additional sources, the IM training manual, and recently written papers posted on the research tab of the Interactive Metronome website (www.interactivemetronome.com). This search resulted in 10 relevant publications related to IM. Table 1 presents an overview of effectiveness of IM and similar Auditory-Motor Integration training.

Table 1. Overview of Effectiveness of Interactive Metronome (IM) training

Author (s)	Study Focus	Sample Size	Quality Measures	Summary of Results
Shaffer et al. (2001)	The IM training on children with ADHD	56 children all males, ages 6-12 years	Conners' rating Scale-R, Achenbach Child Behavior Checklist, The sensory Profile, Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), Wide range Achievement Test, Language Processing Test	53 of 58 measures including areas of attention, motor control, language processing, reading, regulation of aggressive behavior improved following the IM treatment.
Jacokes (2003)	The IM training on motor, language and cognition in children	13 children (ages and gender not available)	Clinical Evaluation of Language Fundamentals (CLEF-3), The Sensory Profile, Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), Self-Perception Profile, Evaluation Tool of Children's Handwriting (ETCH), The Listening Test	Significant gain for auditory processing related to concept and reasoning on Listening Test (p=.003 & .001). Other areas of gain included balance, bilateral coordination, sensory processing, and handwriting. Some areas with no significant change were Self Perception Profile, and ability to transition between tasks.
Alpiner (2004)	The IM training could increase existing auditory-motor processing networks.	Seven adults with experience in training IM and one control adult	Participants were placed in an MRI scanner and were asked to simulate IM cues using the scanners internal cycling noise. Images were taken while this was being done	Increased neural activity in– cingulate gyrus, temporal gyrus, and superior frontal gyrus.
Bartscherer & Dole (2005)	The IM training for improving timing, attention and motor coordination difficulties	Case report nine year old male	Timing and accuracy of various subtests were measured using BOTMP	Changes in timing, fine and gross motor skills, and behaviors as reported by parents.
Etra (2006)	The IM training on children	Eight children {six males}, ages 8-14 years	The IM Long Form Assessment (LFA) Scores, SCAN-C Scores	Significant increase (19%-34%) in LFA and SCAN-C Scores.

Table 1 cont.

Taub et al. (2007)	Effect of Synchronized Metronome Tapping (SMT) intervention on reading achievement in children	86 children (37 males) ages 7-10 years	Woodcock-Johnson III, Comprehensive Test of Phonological Processing, Test of Word Reading Efficiency, and Test of Silent Word Reading Fluency	Scores on selected measures of reading were significantly higher ($p<.001$) in the experimental group.
Ritter et al. (2012)	The IM training in children with language and reading impairment	49 children (34 males), ages 7-10 years	CLEF-4, Core Language Scores, Expressive Vocabulary Test (EVT-2), Gray Oral Reading Test (GORT -4)	The treatment group made larger gains than the control group in areas of reading rate/fluency and comprehension.
Taub et al. (2015)	Effect of improvements in timing/ rhythmicity on mathematics achievement using synchronized metronome beat	86 children, ages 7-10 years	Woodcock-Johnson III Tests of Achievement	Scores on the measures of mathematics were significantly higher ($p<.015$) in the experimental group.
Shank & Harron (2015)	The IM training on timing skills, hand function, and self-regulatory behaviors in children.	48 children (41 males), ages 6-17 years	Jebsen Taylor Test of Hand Function (JTTHF) and the IM Long Form Assessment (LFA)	Improved on timing scores (LFA): 64% ($p<0.0001$), dominant and non-dominant hand (JTTHF): ($p<0.0001$), Parent Questionnaire: 26% ($p<0.0001$).
Reeves & Lucker (2017)	Effectiveness of therapy (Integrated Listening and earphone training, IM, and Phonemic Synthesis training) in Auditory Processing	125 children, ages 5-16 years	Outcome measures included Speech in Noise (SIN), Phonemic Synthesis Test (PST), NU-6 Filtered Words (FW), Pitch Pattern Sequence Test (PPST)	Comparisons of related samples t-tests revealed highly significant ($p=0.0009$) improvements in all areas of auditory processing and IM timing post-therapy.

Review of Research on Interactive Metronome and Auditory-Motor Integration

When considering any therapy for children with auditory processing problems, it is important to examine the theoretic basis of the treatment believed to be effective. Four of the articles reviewed addressed the underlying theory behind IM training (Jacokes, 2003; Etra, 2006; Ritter et al, 2012; Shank and Harron, 2015). Alpiner (2004) suggested that IM training works by augmenting internal processing speed due to its effect on key regions of the cerebellum, prefrontal cortex, cingulate gyrus and basal ganglia. He argued that the inherent neurosensory and neuromotor exercises that are part of IM training helps to improve the brain's inherent ability to repair or remodel itself through neuroplasticity processes. The level of a person's performance on IM that involves planning, timing, and rhythmicity of motor regulation correlates with the severity of developmental, learning, and attentional problems, improvements in academic performance, and age-expected performance changes during the school years (Kuhlman & Schweinhart, 1999). The underlying mechanisms for the gains made through IM training, however, were not well understood. Additionally, recent research (Peterson, 2016; Peterson, Simpson, & Lucker, 2016; Reeves & Lucker, 2017) has demonstrated positive outcomes from IM training on auditory temporal processing and language comprehension, as well as on overall auditory processing including speech understanding in noise, understanding distorted (filtered) speech, and auditory integrative processing.

Mauk and Buonomano (2004) described how temporal processing is inextricably related to sensory processing, auditory processing, motor coordination and control, language development, visual tracking (saccadic eye movements) and behavior. The most sophisticated temporal processing occurs at a 10-100 milliseconds, which is fundamental for auditory and speech processing as well as motor coordination. Thaut et al. (2002) identified research supporting the interaction between rhythm and motor control. These researchers investigated the effect of rhythm on control of paretic arm movements. They found that individuals with a paretic arm showed improvements in timing and trajectory control during structured auditory rhythmic conditions, but not during non-rhythmic conditions. Their data suggested that the use of IM with its structured auditory rhythm could be an effective training tool to enhance sensorimotor control. The IM training improves temporal processing at the 10-100 milliseconds providing better auditory-motor integration and control due to the auditory training (Thaut et al., 2002)

Interactive Metronome has been used as a treatment to improve processing abilities in a variety of disorders. For example, it has been used in individuals with Attention Deficit Hyperactivity Disorder (ADHD), speech and language disorders, balance and gait disorders, traumatic brain injuries, sport and motor disorders, and auditory processing issues (McGrew, 2013; Peterson, 2016; Peterson et al., 2016; Reeves and Lucker, 2017). Research demonstrated that because of IM training, individuals respond more in synch with the rhythmic beat of the metronome improved significantly when compared to baseline results in many areas (McGrew, 2013; Peterson, 2016; Peterson et al., 2016; Reeves and Lucker, 2017). Gorman (2003) and McGrew (2013) also reported improvements in cognitive function and motor skills following IM training. Theoretically the gains observed may have resulted from taking advantage of the neuroplasticity potential of the brain. The IM training works by changing neurocognitive mechanisms within the brain allowing for more efficient processing. This success through improved communication between brain structures within neural networks that are responsible for the cognitive and motor functions necessary during IM training (McGrew, 2013). These brain structures including cerebellum, anterior cingulate, basal ganglia, dorsolateral prefrontal cortex, right parietal cortex, motor cortex, and the frontal-striatal loop are thought to be involved in intellectual and cognitive functioning, working memory, and controlled attention (Lewis & Miall, 2006; Taub, McGrew, Keith, 2007; McGrew, 2013).

Research on IM Training and Other Non-Motor Areas

In addition to looking at changes in motor control and coordination after IM training, Taub, McGrew and Keith (2007) studied the impact of IM training on factors that can affect attention and academic achievement. The researchers looked at sustained attention, ability to tune out distractions (an auditory processing skill), multi-tasking, working memory, impulse-control and self-monitoring, mental processing speed, executive functions (meta-cognition), and academic achievement. Taub et al.'s research demonstrated cognitive improvements after 12 sessions of IM. They believed that IM had an impact on the timing structures of the brain, mostly, in the cerebellum and basal ganglia (Mauk & Buonomano, 2004) known for temporal processing, and that IM is one of the only intervention that works on timing at a level of a 10-100 milliseconds. Therefore, it was believed that IM could benefit children with temporal processing deficits, such as those found in children diagnosed with ADHD and Autism Spectrum Disorder (ASD).

Several other researchers examined the effects of IM on ADHD behavior. Leisman and Melillo (2010) examined the effects of IM training on male, school-aged children with ADHD. Using a signal detection task in which children were asked to detect the presence of a signal and the letter U on a computer screen (an auditory-visual integration attention measure) by pressing the appropriate key on the keyboard; the researchers evaluated the change in attention in children who underwent IM training. The children were awarded points for correct responses and lost points for incorrect responses. They included four groups of children: children with ADHD treated with IM, children with ADHD receiving no IM treatment, children with typical functioning who received IM treatment, and a control group of children with typical development who received no IM treatment. Comparison of pre-treatment and post-treatment signal detection scores revealed little change for children without ADHD. However, significant changes in performance were observed in the ADHD group receiving IM treatment. Their ability to correctly identify the signal improved while the number of false alarms and misidentification of signals being present decreased following IM training.

Shaffer et al. (2001) found improvements in several areas following IM training with children who had ADHD. The researchers examined three groups of male students, aged 6 to 12, with ADHD; one group who received IM treatment, one group assigned to play a computer-based video game, and a control group who did not receive any intervention. Multiple measures were used to examine attention and concentration, clinical functioning, and academic and cognitive skills pre- and post-intervention. The results revealed that those students with ADHD who received IM training showed significant improvements in the areas of attention, motor control, language processing, reading ability, and ability to control aggression when compared to participants in the video game or control group. Thus, research has demonstrated significant improvements in motor control and coordination using IM, an auditory-based training tool.

Research Findings Related to Interactive Metronome and Auditory Processing Disorders

In view of the improvements in motor coordination and control, academic achievement, and attention factors found with IM training, a question arises as to changes that may be seen in auditory processing abilities. Can IM be used effectively as a treatment for auditory processing disorders, especially in children?

There is limited published data on using IM for the treatment of auditory processing disorders. Etra's (2006) research focused on whether IM training would change auditory processing abilities in children. Six male and two female students between the ages of 8-14 who demonstrated deficits in attention, but had not been diagnosed with ADHD or auditory processing disorders, were recruited into the study. Etra (2006) used IM training and then examined the children's performance on the SCAN-C Test for Auditory Processing Disorders in Children Revised (Keith, 2000), a test that evaluates auditory processing abilities. SCAN-C performance was assessed prior to and following 15 to 17, one hour IM training sessions. The SCAN-C includes four measures of auditory processing: two of which are monaural tests of low redundancy using filtered word (distorted speech), a measure of speech understanding in noise (auditory-figure ground) and two dichotic listening tests using competing words (auditory integration) and competing sentences (auditory separation).

In a recent unpublished doctoral dissertation Peterson (2016) and Peterson et al. (2016), looked specifically at auditory processing and auditory/language comprehension in young adults with traumatic brain injury (TBI). The participants underwent IM training and completed a variety of auditory processing and language tests, including the SCAN-3: A (Adult level version of the updated SCAN test; Keith, 2009). The subtests used included Filtered Speech, Auditory Figure-Ground 0, Competing Words, Competing Words – Directed Ear, Competing Sentences and Time Compressed Sentences (TCS). The TCS is a measure of auditory temporal processing that measures a person's abilities to repeat rapidly presented sentences. The results of post-treatment vs. pre-treatment findings on the SCAN-3: A revealed a highly significant (p=0.0009) improvement in this measure of auditory temporal processing after the IM training supporting the theory that the IM training improves temporal processing in the brain. Additionally, significant improvement was found in auditory/language comprehension based on results from the Computer Revised Token Test – Listening Version (McNeil et al., 2015) and The Discourse Comprehension Test – Second Edition (Brookshire & Nicholas, 1997).

Recently, Reeves and Lucker (2017) looked at a combination of listening therapy (Integrated Listening Systems or iLS www.integratedlistening.com) along with IM training in a large group (N=125) of students (aged 5 to 17 years). All students were evaluated and found to have auditory processing disorders. A variety of auditory processing measures were administered prior to the treatments and included filtered words (NU6 Filtered Words Test), auditory figure-ground (W-22 Speech-In-Noise with a signal-to-noise ratio (SN) of +5), dichotic listening (SSW Test), and auditory temporal processing (Pitch Pattern Sequence Test and IM timing measure). The students underwent iLS and IM treatments and were re-evaluated on each of the same measures. Comparisons of related samples t-tests revealed highly significant (p= 0.0009) improvements in all areas of auditory processing and IM timing post-therapy. Thus, iLS and IM treatments were found to contribute to significant improvements in auditory processing abilities, especially temporal processing/timing, in young adults (Peterson, 2016) and in children and adolescents (Reeves & Lucker, 2017).

Summary of Findings for Interactive Metronome Training

The potential use and efficacy of IM treatment is documented in literature across various disciplines with participant having disorders, including auditory processing and auditory/language comprehension problems. The underlying skill that appears to be most consistently responsive to IM training is temporal processing, although it should be noted that other improvements in auditory processing and motor planning and timing were also observed. Kuhlmann and Schweinhart (1999) discussed that motor planning and timing activities are important for children to improve their social interactions as well as their performance levels in sports, music, dance, speech, and general life functioning. The IM training requires participants to match an auditory based rhythm with other modalities and processes, such as motor activities, language comprehension, correctly repeating what they hear which can help children develop motor and timing skills and improve perception of temporal and spatial cues as well as understanding of linguistic information. Shaffer et al. (2001) provided important evidence that IM training programs, may be helpful in improving timing and rhythmicity related to motor planning and sequencing, as well as improving higher cognitive skills that are important for performance in many areas of education, communication, sensorimotor functioning, and for daily living skills. Etra (2006) found that children with auditory processing disorders showed significant improvement in dichotic listening following 15-hours of IM training. Additionally, Peterson (2016) and Peterson et al. (2016) showed improvements in auditory temporal processing and auditory/language comprehension. Reeves and Lucker (2017) revealed that IM training (along with a listening therapy) significantly improved auditory processing and timing skills in a large sample of students.

Current evidence indicates that IM may be beneficial in improving multiple domains associated with motor planning, attention, auditory processing, language processing, and cognitive functioning. Though more research is required to establish IM training as a valid and reliable treatment method for use in children with auditory processing issues, some of the studies supports its use, especially to improve auditory temporal processing in such children.

Limitations

There are some limitations to the present investigation. This review of previously published material was limited to those publications available through a literature search, as well as some known publications, doctoral dissertations, and presentations at professional meetings. There may be other studies that were not identified.

Another limitation relates to the research methods. Many studies used convenience sampling so if reviewed studies that the participants were not randomly chosen. However, much of the published research focusing on clinical therapies uses convenience sampling or children who are available to the investigators. Using convenience sampling introduces potential biases but likely did not confound the conclusions drawn from the sources examined. Additionally, most of the research compared findings after IM treatment, but did not compare findings with a control group not receiving any IM training. This lack of control makes it difficult to interpret the treatment results.

Because of these identified limitations, future research should consider completing more randomized subject selection and studies using control groups. Such research would add to what is known about the positive outcomes from IM training.

Conclusion

Every child, adolescent, and adult has a unique way of processing information, especially auditory information, and using information for motor planning and sequencing. It is evident that listeners with auditory processing deficits have difficulties understanding auditory-verbal stimuli, which leads to problems comprehending information presented to them in social, work and academic environments. The present review of the literature indicates that the use of a technology (i.e., IM Training) aimed at strengthening motor planning, sequencing, timing, and rhythmicity may have an important role in improving abilities to attend and learn as well as comprehend what is heard (Etra, 2006 ; Peterson, 2016; Peterson et al., 2016; Reeves & Lucker, 2017). However, the present review of the literature indicates that little research has been done investigating the effects of IM specifically on auditory processing issues in children seen by audiologists and speech-language pathologists for evaluations and by speech-language pathologists and occupational therapists for treatment. Thus, there is a need for researchers to further investigate whether IM training is effective for improving auditory processing skills as well as auditory-motor integration, and improving cognitive and executive functions. It is evident from the available data reviewed that IM can help clients accomplish outcomes that improve a wide variety of listening and functional skills.

In conclusion, the literature on IM training suggests that it may have potential usefulness in a wide range of clinical conditions to address attention, motor planning and sequencing, as well as improve auditory processing abilities. As we continue to understand auditory processing issues in children, we will be able to find effective ways to help these children. Auditory-motor integration therapies, like IM, seem to be very useful treatment strategies to address auditory processing problems in children seen in rehabilitative clinical practices.

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Research Article

Development and Validation of a Questionnaire Measuring Functioning Abilities of Older Adults Living with Hearing Disability: Implications for Audiologic Rehabilitation

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Abstract

Diagnosis of hearing loss (HL) reveals little about an individual's disability level, particularly in older adults. That is, individuals with the same magnitude of HL on standardized clinical tests may experience very different effects on their day to day quality of life. A variety of factors associated with HL have been found to influence the relationship between HL and auditory capacities needed for daily communication that are incorporated within the ICF –International Classification of Functioning, Disability, and Health (ICF) – Core Sets for Hearing Loss (CSHL). While the ICF CSHL holds great promise, it is unclear how CSHL classifications could be used in daily clinical practice and with the complex concepts of the ICF system (interaction, bidirectional cause-effect). We created and tested the validity of the first hearing questionnaire based on the ICF CSHL in a community-based cohort of 131 independent older adults who complained of social-communication difficulties. This validated questionnaire measures the presence and magnitude of select factors contained in the CSHL that can be used to improve execution of audiological services, treatment, and rehabilitation.

Keywords: age-related hearing loss; hearing disability; International Classification of Functioning, Disability, and Health; ICF Core Sets projects for hearing loss

Introduction

Diagnosis of hearing loss (HL) reveals little about an individual's disability level when evidence is restricted to routine clinical hearing evaluation data, particularly in older adults. That is, individuals with the same magnitude of HL on standardized clinical tests may experience very different levels of disability. A variety of factors associated with HL have been found to influence the relationship between diagnosis of HL and auditory capacities needed for daily communication. For example, tinnitus, whether occurring before or after the HL onset, is one of the most distressing sensations that causes various somatic, psychological, and cognitive disorders. Despite etiology, tinnitus interferes with auditory function (e.g., hearing clearly, understand people, and follow conversations in a group or at meetings) (Meikle, et al., 2012). This makes people attribute their hearing difficulties to the co-morbid condition of tinnitus (Zaugg, et al., 2002; Henry, et al., 2014). Furthermore, dizziness and imbalance are other unpleasant sensations that carry a substantial impact on independence, physical, cognitive, emotion functions, and activities and participation (Smith, et al., 2005; Grill, et al., 2012; Smith & Zheng, 2013). Given that the most social-communication activities require the dynamic integration of hearing, vision, mind, and movements of head or body in complex environments, hearing difficulty induced by dizziness- or balance-based limitations could be possible. However, studies that show this possible relationship are few, if any. Furthermore, several studies demonstrated how and the extent to which the association between HL and social psychological and cognitive disorders (e.g., isolation, depression, lack of social support, mild cognitive decline, incident demntai) or visual impairment (e.g., visual acuity loss) negatively influence speech understanding (Gatehouse, 1990; Gatehouse & Nobel, 2004; Kricos, 2000, 2006; Denmark, 2005; Tye-Murray, et al., 2010; Pronk, et al., 2013, 2014; Cacioppo & Cacioppo, 2014; Pichora-Fuller, 2016; Pichora-Fuller, et al., 2016). Nevertheless, in a physical environment, abnormal response to background noise (e.g., acceptance noise level) was found in some normal listeners, patients with severe HL, and patients who experience difficulty in coping, such as failure to use their emotional and cognitive control (Crowley & Nabelek, 1996). Acceptance of noise level (ANL) is one of the important predictors of hearing aid outcomes such as use but not speech understanding in noise (Harkrider & Smith, 2005). Thus, there was a suggestion that reduced ability to accept noise level is mediated, in part by lack of cortical/cognitive inhibition (non-auditory peripheral factors) (Harkrider & Smith; 2005; Harkrider & Tampas, 2006; Tampas & Harkrider; 2006).

All together, this implies the likelihood of potential synergistic interactions in which the effect of two or more impairments together is greater than the impact of HL alone (Schum & Beck, 2008). Remarkably, a tool that measures the presence and magnitude of these contributing factors in one index and captures the potential synergistic interactions is currently lacking. To develop such a tool, data was collected and operationalized within the World Health Organization's International Classification of Functioning, Disability, and Health (ICF) framework (WHO, ICF, 2001). In the ICF model, *Functioning* denotes the positive aspects of the interaction between an individual (with a health condition) and that individual's contextual factors (environmental and personal factors). *Disability* denotes the negative aspects of the interaction between an individual (with a health condition) and that individual's contextual factors (environmental and personal factors).

The ICF is a biopsychosocial model of disabilities proposed to complement the International Statistical Classification of Diseases and Related Health Problems (WHO's International Classification of Disease, ICD: 1992-1994). In hearing healthcare (HHC) services, the ICD approach is crucial to classify ear diseases/disorders and to determine appropriate medical or surgical treatment including hearing aids and implantable technologies (e.g., cochlear implant). However, the ICD approach is not the perfect approach to capture what matters to people living with HL, whether measured or perceived. That is, under optimal conditions, only 20-25% of adults who could benefit from hearing aids actually utilize them, and many hearing aids and non-hearing aids users experience residual communication difficulty in their surrounded social and physical environment (National Academies of Science, Engineering, and Medicine report on hearing healthcare, 2016). In a large-scale study that reported the magnitude of HL, the greater self-reported hearing disability, and the unpleasant sensations were significant predictors of entering a hearing evaluation period (Knudsen, et al., 2010). However, these predictors are somewhat problematic. First, while studies have shown that the magnitude of HL was associated with self-reported hearing disability, their disability level was influenced by impact of social isolation, depression, cognitive decline, dementia, neurotic personality trait, and age (Cox, et al., 2007; Lin, et al., 2011; Banh, et al., 2012, Berg & Johansson, 2014; Mick, et al., 2014). Second, such negative characteristics including the unpleasant sensations have a similar trajectory impact on an individual's mental and cognitive health. Therefore, we argue, there is no reason to think that the psychosocial and cognitive difficulties may differ between the three symptoms of HL, tinnitus, and dizziness. However, stratifying these synergistic effects in one index may make measuring treatment outcomes of HL easier to achieve. Additionally, this approach may allow the establishment of the relative value of treatment alternatives.

The ICF, therefore, provides a multidimensional framework for describing and organizing information on functioning and disability. Within the ICF system, there are more than 1,400 generic categories that can be used to describe a wide range of information about health and health-related area. The ICF categories are hierarchically organized. The letters refer to the components (b: body functions, s: body structures, d: activities and participation; and e: environmental factors), followed by one digit indicating the chapter (first level), followed by the code for the second-level categories (two digits), and the third or fourth (one digit each). Unlike the environmental categories, the personal categories were not completely classified by the ICF system for three important reasons; 1) the personal factors have significant cultural variation, 2) the concept of personal factors continues to evolve, and 3) some of the personal factors are already incorporated by body function and environmental domain. Therefore, using the ICF classification system, hearing disability extends beyond a medical diagnosis of HL or ear disease by its incorporation of the impact of the disorder on an individual activity. An illustration of the ICF framework is presented in Figure 1.

Given that the ICF is a generic framework for all types of health conditions, the WHO proposed the development of "Core Sets" projects through a rigorous scientific process which results in the Comprehensive and Brief ICF Core Sets that reflect the functioning and disability of health condition. There are several existing Core Sets for many different health conditions including the HL (for review see: https://www.icf-research-branch.org/download/category/4-icf-core-sets). The development of the ICF Core Sets for HL (ICF CSHL) followed the WHO guidelines and consisted of a preparatory phase and a consensus phase (Phase I) (Danermark, et al., 2010, 2013; Granberg, et al., 2014a, 2014b, 2014c, & 2014d).

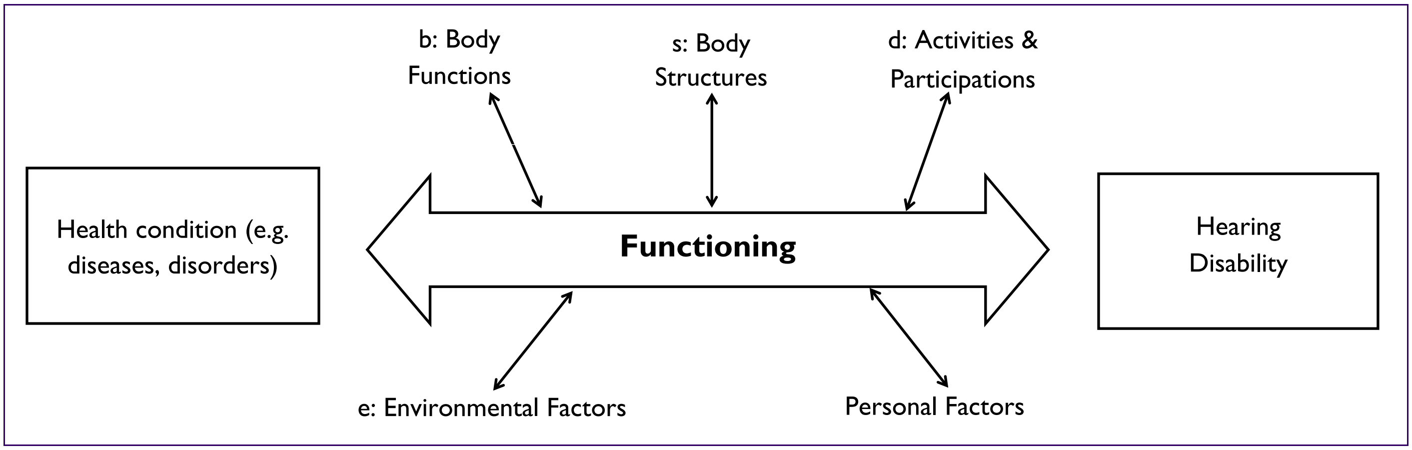

Figure 1: Illustration of the International Classification of Functioning, Disability, and Health framework, which was proposed by World Health Organization in 2001

Phase 1 has been completed and resulted in two Core Sets for HL. The Comprehensive CSHL contains 117 categories and serves as a guide for multi-professional comprehensive assessment. The Brief CSHL includes 27 of the 117 categories and represents the minimal international standard for reporting functioning and disability of persons undergoing hearing evaluation. Phase II is currently ongoing and covers the validation of the CSHL to test if the ICF CSHL could be a useful tool for implementation in clinical practice (Selb et al., 2015). The two differences between the Brief and Comprehensive ICF CSHL are related to 1) the ICF categories that are denoted by the unique alphanumeric codes and 2) by the organization of stem -branch-leaf scheme and interlinked levels. An example is provided in Figure 2.

While the ICF CSHL holds great promise, there are several obstacles to the translation of it into useful clinical tools. For example, the ICF CSHL framework only offers a descriptive system, namely the "ICF coding approach," for classifying health-related information on individuals that can be incorporated into administrative records and databases (ICF manual, 2001; online ICF browser). Grenness, et al., (2016) applied the ICF coding strategy and mapped the ICF categories that matter for an 82-year-old female patient who visited an audiology unit to discuss her hearing difficulties. The mapped ICF categories included the following:

- Among the Body functions: auditory function (b230), tinnitus (b2400), poor attention in background noise (b140, e250), and emotion function (b152), some vision impairment (wears glasses for close-up viewing) (b210, e115).
- Among the Activity limitations and participation restrictions: Conversations with family and friends (d115, d350, d310, d760), Using communication devices and techniques (d360), Communicating with - receiving - spoken messages (d310), Listening (d360), Family relationships (d760) [e.g., reduction in attendance at social events such as dinner with friends].

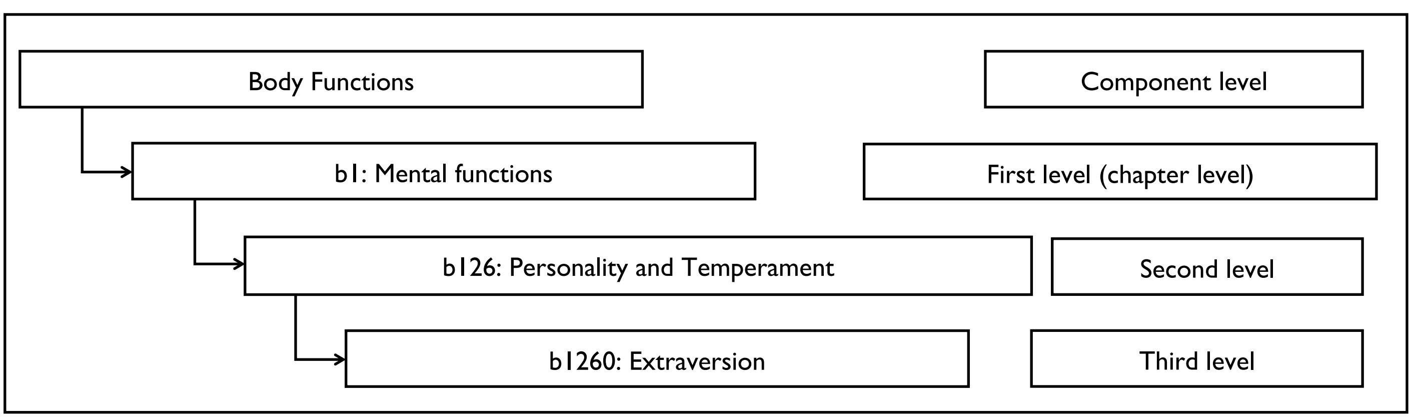

Figure 2: The hierarchical structure of the ICF with examples from the component level body functions. b126: Personality and Temperament is part of the Brief ICF CSHL, while the b1260: Extraversion is part of the Comprehensive ICF

- Among the environmental factors: *Support from immediate family* (e310) [e.g., Lives in an assisted living apartment with husband], *Individual attitudes of immediate family members* (e410).
- Among the personal factors: female, 82-year-old, some arthritis, particularly in right hand (right-handed), three adult children; five grandchildren, two children live nearby; one out of town.

The coding strategy described above is an important analysis system process to identify key elements that facilitate the enablement rehabilitative process and patient- and family-centered hearing care. However, a more structured analysis system to classify and stage functional status across the ICF domains based on the ICF concepts (i.e., synergistic interaction, bidirectional cause-effect) is needed because it will provide a more in-depth reflection of what causes auditory dysfunction beyond hearing loss only.

To classify and stage functional status, the ICF offers a unique "quantitative scaling approach" or "qualifiers" for each domain. The ICF primary qualifier for the classification of body structure and body function domains indicate the degree of impairment on a 5-point rating scale ranging from 0 to 4, with 0 (no difficulty), 1 (mild difficulty, 25% of the time), 2 (moderate difficulty, 50% of the time), 3 (severe difficulty, 75% of the time), and 4 (complete difficulty, 95% of the time). There are two additional qualifiers for non-applicable or non-specified information that can be used by clinicians or patients. The qualifiers for the environmental factors are somewhat unique to quantify barriers and facilitate aspects. This system uses a 9 point scale: –4 (complete barrier, 95% of the time), –3 (severe barrier, 75% of the time), –2 (moderate barrier, 50% of the time), –1 (mild barrier, 25% of the time), 0 (neutral), +1 (25% a facilitator), +2 (50% a facilitator), +3 (75% a facilitator), +4 (95% a facilitator).

Al Fakir, et al. (2015a, 2015b) applied the "ICF coding approach" and the "ICF quantitative scaling approach" to identify the CSHL categories described in the patients' records of a university clinic specializing in amplification and cochlear implantation. Additionally, authors sought to determine if the identified categories support the ICF concept. They found the ICF measurement strategies to have a sufficient internal consistency (Cronbach's $\alpha = .72$). More importantly, beside the hearing aid use, authors identified the CSHL categories that discriminate between successful versus unsuccessful treatments for individuals with HL which are, speech reading [*Using communication techniques* (d3602)] and active social life [(*community life* (d910), s*ocializing* (d9205)]. These findings provided preliminary evidence that the quantitative scaling approach has discriminant validity, which provides a method to segregate and categorize hearing healthcare outcomes according to their measured value. However, a less resource intensive method that reflects real patient's perspective about their health status would be a desirable method to implement the ICF CSHL. One solution would be to develop some form of a self-assessment tool. The primary goal of this paper was to report on the creation of ICF CSHL-based questionnaire and to test its feasibility, internal consistency and validity. Other aims were to assure the questionnaire was clinically useful, and to validate the questionnaire developed.

Methods

Study design

This cross-sectional study was approved by the University of Florida Institutional Review Board according to the Declaration of Helsinki on the statement on ethical principles for medical research involving human participants. Individuals who experienced social-communication difficulties in their daily life, the age between 60-89, who had adequate command of the English language, and independent to complete the tasks were included in the study. Individuals who were unable to complete the study because of the cognitive barrier were excluded. Participants were recruited from the community through flyers and postcards sent to the University of Florida Audiology clinics, University of Florida-Institute of Aging, University of Florida Health-Street program that gives people a voice in ongoing health research, local senior citizen centers, local audiology clinics, and senior living housing developments. One hundred and thirty-one independent-living older adults between 60 and 89 years of age (mean [SD], 72.32 [6.83]), participated in this investigation. After providing written informed consent, participants completed a pen-paper version of the ICF-based questionnaire and comprehensive, standardized and clinically accepted measures similar to the global construct of single-item scale. All testing was completed in one session according to participants' daily functioning (e.g., use of hearing aid, eyeglasses, and contact lenses), with a break period. For hearing-aid users, the function of hearing aids was checked either by real ear measurement or a listening check to verify that the hearing aid was working appropriately. However, the speech recognition test as a measure to verify performance with actual hearing aids was considered as part of the hearing aid evaluation process. Sample characteristics are presented in Table 1.

Materials

Creation of the ICF CSHL-based questionnaire

A group of audiologists consisted of two experts (RA and AH), and four Doctors of Audiology worked collaboratively and developed the ICF CSHL-based questionnaire. Authors

Table 1. Participant Characteristics (N =131)

Characteristics	N = 131	Mean	SD
Age		72.32	6.83
60-69	52		
70-79	55		
80-89	24		
Sex			
Male	55		
Female	76		
Education level			
12 years	26		
14 - 16 years	53		
>16 years	52		
Work status			
Retired	94		
Employed	28		
Volunteer	9		
Living arrangement			
Live with spouse	86		
Live with relatives	13		
Live alone	32		
Health condition*			
No medical disorder	31		
Chronic medical disorder*	100		
Corrected vision			
Distance	100		
Close	115		
Hearing aids users	38		
Intellectual function (MoCA)			
Normal cognition > 26	77		
MCI < 26	48		
Severe cognitive Decline < 21	6		

* Chronic medical disorders ranked based on most reported: High blood pressure and heart disorders, Arthritis, Thyroid disorders, Glaucoma, Meniere's disease, Cancer and its management, Psychological problems (Depression, Anxiety, and Sleep disorder).

determined that a large number of categories in the ICF comprehensive CSHL (*n* = 117) was too extensive for the purposes of this study. Fortunately, the ICF Brief CSHL (*n* = 27) is more clinically applicable. Thus, the ICF Brief CSHL was adopted to initiate development of the questionnaire. However, the ICF CSHL-based questionnaire was designed to sample 22 of the 27 ICF categories of the Brief CSHL. In some cases, the ICF second-level category (b240) *sensations associated with hearing and vestibular function* was parsed to allow for a question addressing *"tinnitus"* (b2400) and *"dizziness"* (b2401) sensations. In other cases, the ICF third-level categories were unparsed, such as *Personality and Temperament function* (b126), in which the single-item scale was defined with fewer details as compared to comprehensive personality measure that classifies personality traits listed in the comprehensive ICF CSHL. Also, some categories were excluded, because authors perceived that it was not feasible to be measure such as [*Structure of brain* (s110), *Structure of external ear* (s240), *Structure of middle ear* (s250), *Structure of inner ear* (s260)]. Also was deemed irrelevant to older adults *School education* (d820).

Operationalization of the data model was guided by feasibility rather than the efficiency and granularity. For feasibility, the questions were created by using the standardized ICF terminology (textual definitions) and inclusion/exclusion criteria for each category after considering as described in ICF manual, 2001 and online ICF browser (http://apps.who.int/classifications/icfbrowser/). Also, we applied the single item scale approach using the ICF qualifiers specified for each domain as described above. Each item was formulated as a question on a 5-point Likert scale based on the "ICF quantitative scaling approach" described above. For efficiency and granularity, we selected a clinically accepted measurement similar to each single-item scale. For example, *Hearing Functions* (b230) have five sub-categories [*Sound detection* (b2300), *Sound discrimination* (b2301), *Localization of sound source* (b2302), *Lateralization of sound* (b2303), *Speech discrimination* (b2304)]. In terms of feasibility, we used one single-item scale "What is the extent to which you can understand the speech of significant others in noise or over distance?" in terms of efficacy, we selected three instruments, the pure-tone audiometry, speech audiometry, and self-reported measure of hearing function. Another example, *Personality and Temperament function* category have five-sub categories [*Extraversion* (b1260), *Agreeableness* (b1261), *Conscientiousness* (b1262), *Psychic stability or Neuroticism* (b1263), and *Openness* (b1264)]. In terms of feasibility, *Personality and Temperament function* was measured by the ICF single-item scale "What is the extent to which your personality or mood distinguish you from others?" In terms of efficiency and granularity, the Big Five Personality Inventory 44 -item was selected to provide an in-depth reflection of the five -sub categories.

The authors chose this procedure for three main reasons: 1) to validate the ICF CSHL-based questionnaire, 2) to test the effectiveness of this procedure, and 3) to guide the enhancement of questionnaire that can be made as to the correlation with the corresponding measure in the future study. The standardized and clinically accepted measurement instruments are classified and described below. The selection of clinically accepted measurements was conducted based on available psychometric information (e.g., internal consistency, reliability, test-retest reliability, validity), correlation with HL, self-reports, audiologic outcomes, and guidelines provided by American Academy of Audiology Clinical Practice in 2015, which is beyond of description in this paper.

Self-Assessments ICF Core Sets for Hearing Loss Questionnaire

Instructions: The purpose of this questionnaire is to identify problems you are having that may affect your daily listening-conversational activities (communicative interaction). Please circle the number that corresponds with the severity and restriction level of the problem. *If you use hearing aids, please answer the way you hear while using the hearing aids.

Body function domain

What is the extent to which your personality or mood distinguish you from others?

0= Never 1= 25% of the time 2= 50% of the time 3= 75% of the time 4= 95% of the time

What is the extent to which you can maintain your focus for a period of time or on two or more things at the same time?

0= Never 1= 25% of the time 2= 50% of the time 3= 75% of the time 4 = 95% of the time

What is the extent to which you can remember things and recall new information?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you feel unhappy or depressed?

0= Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you can see friends over a distance (within 6 feet)?

0= Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you can understand the speech of significant others in noise or over distance?

0= Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you have ringing in your ears

0= Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you feel dizzy or imbalanced?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

Activities limitations and participation restrictions domain

What is the extent to which you have difficulty listening to the television, radio, or movies?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you have difficulty understanding a statement or question during communication activity?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you have difficulty starting, continuing, or ending a conversation, or speaking with several people in a group?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you have difficulty to use coping communication strategies (e.g., ask to repeat, rephrase, read lips, reposition your body or head, etc.)?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you have difficulty maintaining family relationships?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

What is the extent to which you have difficulty socializing with your family or friends?

0 = Never 1 = 25% of the time 2 = 50% of the time 3 = 75% of the time 4 = 95% of the time

Environmental domain

If you think about your environment, how would you rate the usefulness of the hearing technology you use during listening-conversation activities? (☐I am not a hearing aids user)

No, it was barrier				Neutral	Yes, it was facilitator			
-4	-3	-2	-1		+1	+2	+3	+4
95%	75%	50%	25%	0	25%	50%	75%	95%

If you think about your environment, how would you rate the level of background noise during listening-conversation activities?

It was barrier				Neutral	It was acceptable			
-4	-3	-2	-1		+1	+2	+3	+4
95%	75%	50%	25%	0	25%	50%	75%	95%

If you think about your environment, how would you rate the support you received from the close family members during listening-conversation activities?

No, it was barrier				Neutral	Yes, it was facilitator			
-4	-3	-2	-1		+1	+2	+3	+4
95%	75%	50%	25%	0	25%	50%	75%	95%

The instruments were a combination of objective and subjective measurement instruments.

Measures

1. Hearing function

- ***Sound detection (b2300):*** The Pure-tone average (PTA) test was conducted using the Hughson Westlake technique with a GSI-61 audiometer (Grason-Stadler Inc). Air conduction thresholds (250 Hz to 8.00 KHz) were determined with ER-3A Insert earphone or supra-aural headphones (TDH-39). Before audiometry test, otoscopy was completed at the beginning of the session using a Welch Allyn otoscope. Hearing thresholds were averaged for the four speech frequencies (500, 1,000, 2,000, and 4,000Hz).
- ***Speech discrimination (b2304):*** The Bamford-Kowal-Bench speech-in-noise test (BKB-SIN) developed by the Etymotic Research group (2005) to estimate a person's auditory capacity/performance in recognizing the spoken-language in everyday listening conditions with and without hearing aids The BKB-SIN test was presented via a wall-mounted speaker in the sound field that was routed through the GSI-61 audiometer and positioned at 00 Azimuth at a distance of one meter from the participant's approximate head position. BKB-SIN recordings were presented in the sound field at 70 dB HL. All participants completed the two pair list (No. 3 and 4). Participants' scores of each list were recorded as Signal-to-Noise Ratio (SNR). The SNR Scores of the two pair were averaged, and SNR loss was calculated. Scores above 3dB indicated impaired hearing.
- **Activities limitations-related hearing categories: [*Listening (d115), Communication-receiving-spoken-message (d310), Conversation (d350), and Using communication techniques (d3602)]:*** The 49-items version of the Speech, Spatial, and Quality of Hearing Scale (SSQ) developed by Gatehouse and Noble (2004) to measure a range of hearing disabilities across several domains, including hearing speech, spatial hearing, and quality of sound. The SSQ test was completed via pen-paper administration. Lower scores indicate a high level of hearing disability.

2. Sensations associated with hearing and vestibular function

- ***Tinnitus (b2400):*** The Tinnitus Functional Index (TFI) developed by Meikle, et al., (2012) to measure the impact of bothersome tinnitus sensation that could be associated with HL. The subscales include emotional and cognitive stress, the intrusiveness of tinnitus, hearing problems, sleep disorders, and somatic symptoms. The TFI test was completed via pen-paper administration. Scores of 18 and higher indicated mild to severe bothersome tinnitus sensation and greater functional impairment.
- ***Dizziness (b2401):*** The Dizziness Handicap Inventory (DHI) developed by Jacobson and Newman (1990) to evaluate the self-perceived handicapping effects across physical, functional, and emotional, domains imposed by dizziness and unsteadiness sensation. DHI test was tested in patients with peripheral and central vestibular disorders, multiple sclerosis, brain injury, and movement and gait disorders. The DHI was completed via pen-paper administration. Scores of 16-34 indicated mild handicap, of 36-52 indicated moderate handicap, and 54+ indicated severe handicap.

3. Visual Acuity Function

- ***Binocular acuity of distant vision (b2100):*** An Ultimate Snellen eye chart was completed according to their functioning with eyeglasses or contact lenses as used on a daily basis. The Ultimate Snellen eye chart was presented at six feet from the eye. Low visual acuity test scores indicated good binaural eyesight.

4. Mental (Cognitive, psychological) Functions

- ***Global mental functions categories (b110-b139):*** The Montréal Cognitive Assessment version 7.1 (MoCA) developed by Nasreddine, et al., (2005) to assess different cognitive domains: attention and concentration, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. The MoCA test is a cognitive screening tool that evaluates global mental capacity and detects mild cognitive impairment and determines who is at risk for Alzheimer's disorder. The MoCA test was administered via researcher and participant interface according to the recommendations presented by Dupuis and colleagues (2015). Scores less than 26 (25.2 – 19.0) indicate mild cognitive impairment and any score range from (21.0 – 11.4) is considered at risk for Alzheimer's disorder.
- ***Attention function (b140): divided attention (b1402):*** The Brief Test of Attention (BTA) developed by Schretlena, et al. (1996) to provide a rapid assessment of divided attention capacity in different age-band. BTA test consists of two parallel forms: Form N (Numbers) and Form L (Letters). The respondent's task is to disregard the letters presented in Form N (Numbers) and cognitively count how many numbers were read aloud; whereas in the Form L (Letters) the respondent must disregard the numbers and cognitively count how many letters were read aloud. The number of correctly monitored lists is summed across both forms, with raw scores ranging from 0-20. The BAT was presented via a wall-mounted speaker in the sound field that was routed

through the GSI-61 audiometer and positioned at 0° azimuth at a distance of one meter from the participant's approximate head position. The BAT recordings were presented in the sound field at 70 dB HL. High BTA scores indicate a good capability of divided attention.

- ***Attention function (b140) and Memory function (b144):*** The Digit Span Test-Backward (DSB) developed by Wechsler (1997) to measure working memory function. However, Groth-Marnat and Baker (2003) suggested that higher DSB scores can be used to measure everyday attention function and scores would indicate excellent attention and good working memory. The DSB was presented by visual-only modality at a rate of one digit per second via a desktop Dell computer. The recording list consisted of eight sets or 16 trials. The score was the total number of correct trials before failing two consecutive trials at any one span size.
- ***Emotional function (b152):*** The Geriatric Depression Scale (GDS) developed by Yesavage, et al., (1983) to screen for clinical depression among the elderly. The GDS test was completed via pen-paper administration. Higher scores above 10 indicate the presence of depressive symptomatology.

5. *Personality and Temperament function (b126):*

- The Big Five Personality Inventory 44-item (BFPI) developed by Goldberg (1993) to measure the following sub-categories: *Extraversion* (b1260), *Agreeableness* (b1261), *Conscientiousness* (b1262), *Psychic stability or Neuroticism* (b1263), and *Openness* (b1264). The PFPI test was completed via pen-paper administration. Higher scores in extraversion, agreeableness, conscientiousness, and openness, indicate independence, cognitive flexibility, and emotional stability and energy. Higher scores in neuroticism indicate negative emotions such as anger, embarrassment, depression, stress, and anxiety.

6. Social Function

- ***Family relationships (d760):*** The Relationship Assessment Scale (RAS) developed by Hendrick (1988) to assess family relationship. The RAS test was completed via pen-paper administration. Higher scores indicate the ability to maintain relationships with family members, including significant others as well as extended family relationships such as siblings and cousins.
- ***Community life and Socializing (d910):*** The De Jong Gierveld Loneliness and Social Isolation Scale (DJG-LSIS) developed by De Jong Gierveld and Kamphuis (1985) to gauge social and emotional isolation that encompasses a sense of emptiness and missing having people around, with the presence of people to rely on, trust and feel close to them. The DJG-LSIS test was completed via pen-paper administration. Thus, lower scores may indicate an inadequate social network.

7. Personal and environmental factors

- ***Personal factors:*** A short survey attached to the ICF-based questionnaire and includes information about age, gender, education level, work status, living arrangement, health condition, hearing assistive technologies (use per hour, per day, per year) and overall satisfaction.
- ***Environmental factors (e125)***
  - ***Products and technology for communication:*** The hearing aid benefit was indicated by BKB-SIN test and SSQ scores.
  - ***Sound (e250): Sound (noise) intensity (e2500):*** The Acceptable Noise Level test (ANL) was developed by Nabelek and colleagues (1991). The ANL test was conducted in the sound field. The setup was similar to BKB-SIN test. Lower scores indicate background noise intolerance. The rationale for selecting this measure is based on the ANL studies that showed no correlation between personal factors (e.g., age, gender), hearing tests (e.g., hearing sensitivity, acoustic reflex thresholds or contralateral suppression of otoacoustic emissions, speech understanding in noise scores), and the type of noise background noise distraction or preference for background sounds (Freyaldenhoven et al., 2006; Freyaldenhoven, 2007).
  - ***Support and relationship: Immediate family (e310), Extended family (e315), Friends (e320):*** The Lubben Social Network Scale-Revised version of the 12-items scale (LSNS-R-12) was developed by Lubben and Gironda (2004) to measure perceived social support received by family and friends and to gauge social isolation in older adults. The LSNS-R-12 test was completed via pen-paper administration. Higher scores indicate positive support and an adequate social network.

Statistical Analyses

All the statistical analyses were completed using the SPSS version 24 IBM software. We computed the mean, standard deviation, and score range for ICF single-item scales per groups (normal listeners, hearing-aid users, and non-hearing-aid users) as well as for independent instrument measurements. The feasibility of using the questionnaire was measured by the percent of patients who filled out the questionnaire without assistance, and when completed, whether there were any missing items. We checked validity by Pearson correlation coefficient and exploratory factor analyses (EFA). Concurrent validity was evaluated by whether the scores of each single-item of ICF CSHL-based questionnaire aligned and correlated with scores of the corresponding measurement. Construct validity was determined by whether the questions of the ICF CSHL-based questionnaire correlated with the audiologic measures used in this study (PTA: audiometric thresholds, BKB-SIN: laboratory measure of speech understanding in the presence of background noise, and SSQ: self-reported measures of performance in speech, spatial, and qualities of hearing in daily life). The overall validity was determined by how well the questionnaire items captured potential synergistic interactions.

Results

Feasibility and Internal consistency

All the participants completed an ICF CSHL-based questionnaire without assistance in its entirety. The 23 items of an ICF CSHL-based questionnaire have a good internal consistency (Cronbach's α = .83) (Al Fakir's doctoral dissertation, 2016). In this paper, however, we used the same dataset and only a subset of an ICF CSHL-based questionnaire, consisting of 17 single-item scales, based on the availability of standardized and clinically accepted measurement instruments that are similar to the global construct of each single item scale. The internal consistency of the 17 items remains intact (Cronbach's α = .83). Table 2 shows the included and excluded second-level categories of the ICF Brief CSHL.

Table 2. The 23 ICF categories of the Brief CSHL included in Al fakir's doctoral dissertation (2016). The italic formant represents the 17 ICF categories included in this paper

Chapter	Number	Category Description	Included	Excluded
		Body Structure and Body Function		
s	110	Structure of brain		x
s	240	Structure of external ear		x
s	250	Structure of middle ear		x
s	260	Structure of inner ear		x
b	*125*	*Temperament and personality function*	x	
b	*140*	*Attention function*	x	
b	*144*	*Memory function*	x	
b	*152*	*Emotional function*	x	
b	*210*	*Seeing function*	x	
b	*230*	*Hearing function*	x	
b	*240*	*Sensations associated with hearing and vestibular function*	Parsed to	
b	*2400*	*Tinnitus*	x	
b	*2401*	*Dizziness*	x	
		Activities and Participation		
d	115	Listening	x	
d	240	Handling stress and other psychological commands	x	
d	*310*	*Communicating with–receiving–spoken messages*	x	
d	*350*	*Conversation*	x	
d	*360*	*Using communication devices and techniques*	x	
d	*760*	*Family relationships*	x	
d	820	School education		x
d	850	Ruminative employment	x	
d	*910*	*Community life*	x	
		Environmental Factors		
e	*125*	*Products and technology for communication*	x	
e	*250*	*Sound*	x	
e	*310*	*Support from Immediate family*	x	
e	355	Support from Health professionals	x	
e	410	Individual attitudes of immediate family members	x	
e	460	Societal attitudes	x	
e	580	Health services, systems, and policies	x	

*ICF Chapter Key: "b" = body function, "d" = activity and participation, "e" = environment, "s" = structure

Validity

1. Criterion Validity

The percentage of the responses to the ICF 17-items among the 131 participants was calculated. The complaints reported most often among participants within the body functions domain were: working memory (ICF-Q3: 81%), understanding speech in noise or over distance (ICF-Q6: 75.6%), and personality and temperament (ICF-Q1: 64%). The complaints reported most often among participants within the activity limitation/participation restriction domain were: using communication techniques (ICF-Q12: 60%), listening and communication with-receiving-spoken messages (ICF-Q9 and ICF-Q10: 52%), and conversation (ICF-Q11: 46%). Within the environmental domain, the majority of participants reported that perceived level of background noise was a substantial barrier. These complaints were found in (normal listeners, untreated HL, and treated HL). Full details of these findings are presented in Table 3.

2. Concurrent validity

2.1 Descriptive statistics for the ICF CSHL-based questionnaire and clinically accepted measurement instruments

Table 3. Percentage of the responses to the ICF 17-items among the 131 participants

Item Summary	Frequency Distribution and Percentage (N=131)				
Body Functions	0	1	2	3	4
b126 Temperament and personality function	67 (51.1%)	47 (35.9%)	11 (8.4%)	5 (3.8%)	1 (.8%)
b140 Attention function	71 (54.2%)	48 (36.6%)	6 (4.6%)	5 (3.8%)	1 (.8%)
b144 Memory function: *b1440* Short-term memory	25 (19.1%)	76 (58%)	22 (16.8%)	7 (5.3%)	1 (.8%)
b152 Emotional function	73 (55.7%)	40 (30.5%)	9 (6.9%)	6 (4.6%)	3 2.3%)
b210 Seeing function: *b2100* Binocular acuity of distant vision (within 6 feet)	94 (71.8%)	27 (20.6%)	6 (4.6%)	3 (2.3%)	1 (.8%)
b230 Hearing function: *b2304* Speech discrimination	32 (24.4%)	49 (37.4%)	32 (24.4%)	14 (10.7%)	4 (3.1%)
b240 Sensation associated with hearing function: *b2400* Tinnitus	78 (59.5%)	22 (16.8%)	14 (10.7%)	7 (5.3%)	10 (7.6%)
b240 Sensation associated with vestibular function: *b2401* Dizziness	107 (80.2%)	17 (13%)	5 (3.8%)	3 (2.3%)	1 (.8%)
Activity limitations and participation restriction					
d115 Listening	56 (42.7%)	46 (35.1%)	17 (13%)	8 (6.1%)	4 (3.1%)
d310 Communicating with-receiving- spoken-message	62 (47.3%)	52 (39.7%)	12 (9.2%)	4 (3.1%)	1 (.8%)
d350 Conversation	71 (54.2%)	42 (32.1%)	8 (6.1%)	8 (6.1%)	2 (1.5%)
d360 Using communication techniques	52 (39.7%)	39 (29.8%)	15 (11.5%)	18 (13.7%)	7 (5.3%)
d760 Family relationship	94 (71.8%)	31 (23.7%)	5 (3.8%)	1 (.8%)	0
d850 Remunerative employment	125 (95.4%)	5 (3.8%)	1 (.8%)	0	0
d910 Community life: *d9205* Socializing	97 (74%)	25 (19.1%)	4 (3.1%)	5 (3.8%)	0

ICF qualifiers for body functions domain: [0 (no impairment), 1 (mild impairment), 2 (moderate impairment), 3 (severe impairment), and 4 (complete impairment)]. ICF qualifiers for activity limitations domain: [0 (no difficulty), 1 (mild difficulty), 2 (moderate difficulty), 3 (severe difficulty), and 4 (complete difficulty)].

Table 3 cont.

Environmental Factors	Barrier				Neutral		Facilitator		
	-4	-3	-2	-1	0	+1	+2	+3	+4
e125 Products and technology for communication: Hearing aid users (*n*=38)	0 (0%)	2 (5%)	1 (5%)	4 (10%)	3 (7%)	3 (7%)	10 (26%)	10 (26%)	5 (13%)
e250 Sound: *e2500* Sound (noise) intensity (*n*=131)	4 (3%)	18 (14%)	46 (35%)	42 (32%)	21 (16%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
e310 Support from immediate family (*n*=131)	1 (1%)	0 (0%)	1 (1%)	12 (9%)	49 (37%)	19 (14%)	15 (11%)	16 (12%)	18 (14%)

ICF qualifiers for environmental factors: [–4 (complete barrier, 95% of the time), –3 (severe barrier, 75% of the time), –2 (moderate barrier, 50% of the time), –1 (mild barrier, 25% of the time), 0 (neutral), +1 (25% a facilitator), +2 (50% a facilitator), +3 (75% a facilitator), +4 (95% a facilitator)

The mean, standard deviation (SD), and scores range for the 17-items ICF CSHL-based questionnaire and the clinically accepted measurement instruments were calculated per stratified groups. The participants stratified into three groups: normal listeners, untreated HL (non-hearing aid users), and treated HL (hearing aid users). Thirty-seven participants had normal hearing thresholds (< 25dB Hearing Level) for frequencies ranging between 0.25-8.00 kHz in both ears). Fifty-six participants within the untreated HL group demonstrated a range of hearing thresholds, averaged across 500, 1, 2, 4 kHz of each ear, from 10 dB HL to over 47 dB Hearing Level as defined by the better ear. Thirty-eight participants within the treated HL group demonstrated a range of hearing thresholds, averaged across 500, 1, 2, 4 kHz of each ear, from 10 dB HL to over 88 dB Hearing Level as defined by better ear. Full details of scores are presented in Table 4 and 5.

Table 4. Mean, standard deviation (SD), and scores range for the 17-items ICF CSHL-based questionnaire

ICF categories	Groups								
	Normal (n= 37) HL (mean=14, SD =4.7 defined by BE)			Untreated HL (n= 56) HL (mean=28, SD =7.7 as defined by BE)			Treated HL (n= 38) HL (mean=44, SD =17.3 defined by BE)		
	Min-Max	Mean	SD	Min-Max	Mean	SD	Min-Max	Mean	SD
Temperament & Personality Function	0 – 4	.46	.86	0 – 3	.70	.78	0 – 3	.84	.88
Attention Function	0 – 3	.38	.63	0 – 3	.59	.75	0 – 4	.84	.97
Memory Function	0 – 3	.92	.68	0 – 3	1.0	.72	0 – 4	1.4	.91
Emotional Function	0 – 3	.54	.80	0 – 3	.61	.80	0 – 4	.89	1.2
Hearing Function	0 – 3	.57	.76	0 – 4	1.3	.94	0 – 4	1.9	1.0
Seeing Function	1	.11	.31	0 – 3	.50	.78	0 – 4	.53	.92
Tinnitus sensation	0 – 3	.35	.75	0 – 4	.91	1.3	0 – 4	1.2	1.4
Dizziness and Imbalance sensation	1	.05	.22	0 – 3	.30	.65	0 – 4	.55	1.0
Listening	2	.27	.50	0 – 4	1.1	1.0	0 – 4	1.2	1.1
Communication	1	.19	.39	0 – 3	.77	.78	0 – 4	1.1	.92
Conversation	0 – 3	.30	.70	0 – 3	.73	.86	0 – 4	1.0	1.1
Using Communication Techniques	0 – 4	.41	.86	0 – 4	1.3	1.2	0 – 4	1.6	1.2
Family Relationship	1	.27	.45	0 – 3	.30	.63	0 – 2	.45	.64
Community Life	0 – 3	.30	.66	0 – 3	.29	.68	0 – 3	.55	.83
Technology	NA	.00	.00	NA	.02	.48	-3 – 4	1.5	1.8
Background noise	-3 – 0	-1.0	.85	-3 – 0	-1.4	.95	-4 – -1	-2.2	.88
Family Support	-1 – 4	1.0	1.6	-1 – 4	1.0	1.4	-4 – 4	1.3	2.0

Table 5. Mean, stranded deviation, and scores range for the independent measurements linked to the 17-items of the ICF CSHL-based questionnaire

ICF categories	Groups								
	Normal (n= 37) HL (mean=17.0, SD=4.7)			Untreated HL (n= 56) HL (mean=37.3, SD=9.7)			Treated HL (n= 38) HL (mean=54.4,SD=17.4)		
	Min-Max	Mean	SD	Min-Max	Mean	SD	Min-Max	Mean	SD
BFPI (Extroversion)	11 – 39	26.0	6.8	12 – 40	26.1	7.2	14 – 40	27.4	6.3
BFPI (Agreeableness)	21 – 45	37.2	5.5	27 – 44	36.6	4.3	18 – 45	35.9	5.4
BFP (Conscientiousness)	24 – 45	35.6	5.3	22 – 45	35.5	5.8	24 – 46	35.0	5.37
BFPI (Neuroticism)	8 – 32	19.5	6.5	8 – 37	19.0	7.2	8 – 43	20.0	7.1
BFPI (Openness)	23 – 50	37.6	7.0	20 – 48	37.1	7.1	23 – 47	38.5	5.8
Brief Test of Attention	11– 20	17.11	2.5	2 – 20	15.6	4.4	2 – 20	12.5	4.6
Digit Span Test-Backward Visual	4 – 12	7.2	1.9	3 – 12	6.8	2.0	3 – 13	6.8	2.2
Montreal Cognitive Assessment	22 – 30	27.0	2.0	20 – 30	26.3	2.6	18 – 30	26.3	2.7
Geriatric Depression Scale	0 – 20	4.8	5.5	0 – 23	4.8	4.9	0 – 27	6.0	5.8
Bamford-Kowal-Bench-Speech-in-noise	-2.7 –.75	-1.2	.82	-3.0 –6.5	.07	2.0	-2 – 23.5	2.5	5.7
Visual acuity at distance	.4 – 1.0	.86	.18	.4 – 1.0	.83	.19	.4 – 1.0	.83	.20
Tinnitus Functional Index	.0 – 34	2.4	6.4	.0 – 58.8	8.0	14.2	.0 – 53.6	10.9	15.9
Dizziness Handicap Inventory (Total)	0 – 24	4.4	7.0	0 – 58	7.9	11.9	0 – 62	10.8	14.3
Physical Subscale	0 – 8	1.5	2.4	0 – 18	2.8	5.2	0 – 18	3.8	4.2
Functional Subscale	0 – 12	1.8	3.3	0 – 22	3.2	4.5	0 – 28	4.3	5.8
Emotional Subscale	0 – 12	.9	2.4	0 – 22	2.3	4.1	0 – 16	2	3.6
Speech, Spatial, and Qualities Scale (Total)	6.4–9.7	8.41	.95	4.3 – 9.6	7.3	1.4	1.1 – 9.4	6.3	1.8
Speech Subscale	4.0 – 10	7.8	1.4	2.7 – 10	6.4	1.9	.7 – 9.5	5.9	2.1
Spatial Subscale	5.1–10	8.4	1.3	2.6 – 10	7.1	1.6	.9 – 10.3	6.9	2
Qualities of Hearing Subscale	5.5 – 10	8.7	1	4.3 – 9.8	7.8	1.2	1.6 – 10	7.2	2
Relationship Assessment Scale	– 35	31.3	5.0	17 – 35	29.8	5.3	20 – 35	32.1	3.4
DJG-Loneliness and Social Isolation Scale	0 – 11	2.9	3.0	0 – 10	3.1	2.5	0 – 11	3.7	2.9
Acceptable Noise Level	-2 – 12	2.6	3.7	-2 – 12	3.3	4.2	-2 – 12	4.4	3.9
Lubben Social Network Scale -Revised	19– 54	38.7	8.1	9 – 56	37.2	9.9	22 – 51	36.1	7.7

Abbreviations: BFPI: Big Five Personality Inventory, SD: standard deviation, Min: minimum, Max: maximum.

2.2 Pearson Correlation Coefficient between an ICF CSHL-based questionnaire and the instrument measurements

Based on definitions by McLeod (2008) about correlation size, strong (*r* = ± 0.70 and ± 0.9) or moderate (*r* = ± 0.40 and ± 0.69) correlations were found among several questions, while remaining questions fell in the weakly correlated range (*r* < ± .29). Full details of significant and non-significant correlations coefficients between the ICF CSHL items and the scores of other measures are presented in Table 6.

Significant, strong correlations were found between 1) ICF -Q6 and SSQ; 2) ICF-Q7 and tinnitus functional index (TFI). Significant, moderate correlations were found between 1) ICF-Q6 and pure-tone average or BKB-SIN; 2) ICF-Q8 and dizziness handicap inventory (DHI); 3)ICF-Q4 and Geriatric Depression Scale (GDS) and Loneliness sub scale of De Jong Gierveld Isolation Scale (DJG-LSIS), respectively; 3) ICF-Q5 and Snellen chart (far distance); 4) ICF-Q9 trough ICF-12 and SSQ. Additional significant, but weak correlations are also described in Table 6.

Table 6. Pearson correlation coefficient between the items of the ICF CSHL-based questionnaire and the independent measurements

ICF Items	Measure	r (n=131)
Body Functions domain		
Q1.What is the extent to which your personality or mood distinguish you from others?	BFPI: Openness	-.03
	BFPI: Extroversion	-.18*
	BFPI: Agreeableness	-.30**
	BFPI: Conscientiousness	-.23**
	BFPI: Neuroticism	.32**
Q2. What is the extent to which you can maintain your focus for a period of time or on two more things at the same time?	BTA	.34**
	DSB-V	-.30**
	MoCA	-.17*
Q3. What is the extent to which you can remember things and recall new information?	DSB-V	-.21**
	BTA	-.32**
	MoCA	-.25**
Q4. What is the extent to which you feel unhappy or depressed?	GDS	.50**
	LSIS-DJG (Loneliness subscale)	.44**
Q5. What is the extent to which you can see friends over a distance (within 6 feet)?	Snellen chart (far distance)	-.40**
Q6. What is the extent to which you can understand the speech of significant others in noise or over distance?	PTA (average of both ears)	.64**
	BKB-SIN	.57**
	SSQ	-.71**
Q7. What is the extent to which you have ringing in your ears?	TFI	.83**
Q8. What is the extent to which you feel dizzy or imbalanced?	DHI	.51**
	DHI Physical subscale	.48**
	DHI Functional subscale	.50**
	DHI Emotional subscale	.38**
Activities and Participation domain		
Q9. What is the extent to which you have difficulty listening to the television, radio, or movies?	PTA (average of both ears)	.55**
	BKB-SIN	.58**
	SSQ	-.62**
Q10. What is the extent to which you have difficulty understanding a statement or question during communication activity?	PTA (average of both ears)	.62**
	BKB-SIN	.64**
	SSQ	-.65**
Q11. What is the extent to which you have difficulty starting, continuing, or ending a conversation, or speaking with several people in a group?	PTA (average of both ears)	.50**
	BKB-SIN	.53**
	SSQ	-.63**

Table 6 continued

Activities and Participation domain continued		
Q12. What is the extent to which you have difficulty to use coping communication strategies (e.g., ask to repeat, rephrase, read lips, reposition your body or head, etc.)?	PTA (average of both ears) BKB-SIN SSQ	.48** .42** -.50**
Q13. What is the extent to which you have difficulty maintaining family relationships?	RAS LSNS-12 DJG-LSIS (Social subscale)	-.20* -.21* .23**
Q14. What is the extent to which you have difficulty socializing with your family or friends?	DJG-LSIS (total scale) DJG-LSIS (Social subscale) DJG-LSIS (Loneliness subscale) LSNS-12 RAS	.32** .30** .30** -.12 .89
Environment domain		
Q15. If you think about your environment, how would you rate the usefulness of the hearing technology you use during listening-conversation activities? (n=38)	BKB-SIN SSQ	-.18 .22
Q16. If you think about your environment, how would you rate the level of noise background during listening-conversation activities?	ANL	-.30**
Q17. If you think about your environment, how would you rate the support you received from the close family members during listening-conversation activities?	LSNS-12 DJG-LSIS (Social subscale) RAS	.20* -.22* .16

Abbreviations: BFPI: Big Five Personality Inventory; PTA, pure tone audiometry; BKB-SIN, Bamford-Kowal-Bench; TFI, Tinnitus Functional Index; DHI, Dizziness Handicap Inventory; MoCA, Montreal Cognitive Assessment; ANL, acceptable noise level; SSQ, Speech, Spatial, and Qualities of Hearing Scale; GDS, Geriatric Depression Scale; LSNS-12, Lubben Social Network Scale-Revised; Digit Span Test-Backward via Visual modality (DSB-V); DJG-LSIS, De Jong Gierveld Loneliness and Social Isolation Scale; RAS: Relationship Assessment Scale. **Significant $p \leq 0.01$ (2-tailed) *Significant $p \leq 0.05$ (2-tailed)

3. Construct validity

3.1 Pearson Correlation Coefficient between ICF CSHL-based questionnaire along with some personal factors (age, gender, education, living arrangement, health conditions) and (pure tone average, BKB, and SSQ test results)

All the items showed a significant correlation with the PTA, SSQ and BKB-SIN except of the ICF-Q17 (If you think about your environment, how would you rate the support you received from the close family members during listening-conversation activities?) and ICF-Q15 (If you think about your environment, how would you rate the usefulness of the hearing technology you use during listening-conversation activities?) among hearing aids users. We found a significant correlation between age, PTA, and BKB-SIN but not SSQ and between gender and PTA only. Other variables showed no significant correlations. The highest correlation coefficient between the BKB-SIN and ICF items were related to *working memory function* (ICF-Q3), *background noise barrier* (ICF-Q16), *dizziness and imbalance sensations* (ICF-Q8). Whereas the highest correlation coefficient between the SSQ and ICF visual items were related to *attention function* (ICF-Q2), *working memory function* (ICF-Q3), *emotional function* (ICF-Q4), *visual acuity (eyesight) at a distance* (ICF-Q5), *dizziness and imbalance sensations* (ICF-Q8), and *background noise barrier* (ICF-Q16). The correlation coefficients between the ICF CSHL items and the values of specified measures are presented in Table 7.

3.2 Exploratory factor analyses (EFA)

The purpose of this multivariate statistical approach is to explore the underlying structure among this large set of variables related to hearing. To identify common key factors and potential synergistic interactions we ran the EFA by adding variables that cover ICF domains related to hearing. For example, to cover the body structure, we added the pure-tone average (PTA) for worst and better ear. To cover the body functions, activities limitations and participation restrictions, environmental factors, we added the 17 items of the ICF- CSHL-based questionnaire. Since we only had 38 hearing aids users, the ICF-Q15 was replaced by binary classification (1=non hearing aids users, 2=hearing aids users). The Kaiser-Meyer-Olkin measure verified marvelous sampling adequacy (KMO=.90) for the analysis as indicated by Kaiser (1974). Bartlett's test of Sphericity (approximate $\chi 2$ [171, n=131] =1169.1; p<.001) indicated that the relation between items was sufficiently large for the analysis. The Goodness-of-Fit test was adequate [$\chi 2$ (86, n=131) = 70.9, p = .87].

Table 7. Pearson correlation coefficient between 17 ICF items, personal factors, and pure-tone average (PTA), Bamford-Kowal-Bench Speech-In-Noise (BKB-SIN), and SSQ, Speech, Spatial, and Qualities of Hearing Scale

ICF items	Audiologic outcomes		
Body Functional Domain	PTA r (n=131)	BKB-SIN r (n=131)	SSQ r (n=131)
Q1. What is the extent to which your personality or mood distinguish you from others?	.21*	.21*	-.31**
Q2. What is the extent to which you can maintain your focus for a period of time or on two more things at the same time?	.35**	.32**	-.48**
Q3. What is the extent to which you can remember things and recall new information?	.37**	.41**	-.55**
Q4. What is the extent to which you feel unhappy or depressed?	.17*	.23**	-.40**
Q5. What is the extent to which you can see friends over a distance (within 6 feet)?	.26**	.28**	-.52**
Q6. What is the extent to which you can understand the speech of significant others in noise or over distance?	.64**	.60**	-.71**
Q7. What is the extent to which you have ringing in your ears?	.26**	.18*	-.24**
Q8. What is the extent to which you feel dizzy or imbalanced?	.42**	.36**	.46**
Activities and Participation Domain			
Q.9 What is the extent to which you have difficulty listening to the television, radio, or movies?	.54**	.55**	-.62**
Q.10 What is the extent to which you have difficulty understanding a statement or question during communication activity?	.62**	.53**	-.65**
Q.11 What is the extent to which you have difficulty starting, continuing, or ending a conversation, or speaking with several people in a group?	.50**	.41**	-.63**
Q.12 What is the extent to which you have difficulty to use coping communication strategies (ask to repeat, rephrase, read lips, reposition your body or head, etc.)?	.48**	.40**	-.50**
Q.13 What is the extent to which you have difficulty maintaining family relationships?	.17*	.22*	-.40**
Q.14 What is the extent to which you have difficulty socializing with your family or friends?	.25**	.21*	-.35**
Contextual Domain			
Q.15 If you think about your environment, how would you rate the usefulness of the hearing technology you use during listening-conversation activities? (n=38)		-.18	.22
Q.16 If you think about your environment, how would you rate the level of noise background during listening-conversation activities?	-.50**	-.42**	.50**
Q.17 If you think about your environment, how would you rate the support you received from the close family members during listening-conversation activities?	.05	-.11	-.05
Age	.31**	.31**	-.15
Gender	-.23**	-.07	.12
Education	-.08	-.09	.00
Living arrangement	.04	.06	.08
Health condition	.00	.05	.06

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

The model provided a five latent factors solution, which explained 56.4% of hearing disability variances. The first four factors represent a *disability aspect*, while the fifth factor represents a *functioning* aspect of the ICF:

- The key predictors in Factor 1 were: *self-reported hearing impairment/difficulty* (ICF-Q6, ICF-Q9 through Q12), *background noise barrier* (ICF-Q16), and *tinnitus* (ICF-Q7) respectively.
- The key predictors in Factor 2 were: *cognitive and psychosocial impairments* (ICF-Q1 through Q4), *maintaining family relationship difficulty* (ICF-Q13), and *socializing difficulty* (ICF-Q14) respectively.
- The key predictors in Factor 3 were: the *magnitude of HL* as indicated by PTA (hearing sensitivity level) in hearing aids users.
- The key predictors in Factor 4 were: *dizziness and imbalance sensations* (ICF-Q8) and *visual acuity (eyesight) at a distance* (ICF-Q5).
- The key predictors in Factor 5 were: *absence of reported impairments, activities limitations and restrictions, and physical environment and social context barriers.*

The rotated structure matrix demonstrated the inter-correlations between the magnitude of HL as measured by the PTA (hearing sensitivity level) and ICF items:

- Factor 1 showed the involvement of *background noise barrier* (ICF-Q16), *working memory* (ICF-Q3), *visual acuity (eyesight) at distance* (ICF-Q5), *attention* (ICF-Q2), *dizziness and imbalance sensations* (ICF-Q8), *emotion* (ICF-Q4), and *tinnitus* (ICF-Q7) on the connection between magnitude of HL as indicated by measured the PTA (hearing sensitivity level) and self-reported hearing impairment/difficulty as indicated by [ICF-Q6, ICF-Q9 through ICF-Q12). The loading of these items on Factor 1 was > .40 and was ordered respectively.
- Factor 2 showed the involvement of cognitive-psychological difficulties [*Personality and temperament* (ICF-Q1), *attention* (ICF-Q2), *emotion* (ICF-Q4), and *working memory* (ICF-Q3)], *socializing* (ICF-Q14)], *family relationship* (ICF-Q13), *background noise barrier* (ICF-Q16*), visual acuity (eyesight) at a distance* (ICF-Q5), and *dizziness and imbalance sensations* (ICF-Q8) on the connection between magnitude of HL as indicated by the PTA (hearing sensitivity level) and self-reported hearing impairment/difficulty [ICF-Q6, ICF-Q9 through Q12). The loading of these items on Factor 1 was > .40 and was ordered respectively.
- Factor 3 showed the involvement of hearing aid use, *background noise barrier* (ICF-Q16), and *dizziness and imbalance sensations* (ICF-Q8) on the connection between the magnitude of HL as indicated by the PTA (tween the hearing sensitive ty level) and the self-reported hearing impairment/ difficulty [ICF-Q6, ICF-Q9 through Q12). The loading of these items on Factor 1 was > .40 and was ordered re spectively.
- Factor 4 showed the involvement of *dizziness and imbalance sensations* (ICF-Q8), *visual acuity (eyesight) at a distance* (ICF-Q5), *socializing* (ICF-Q14), *emotion* (ICF-Q4), *working memory* (ICF-Q3), *attention* (ICF-Q2) on the connection between magnitude of HL as indicated by the PTA (hearing sensitivity level) and the self-reported hearing impairment/ difficulty [ICF-Q6, ICF-Q9 through Q12). The loading of these items on Factor 1 was > .40 and was ordered respectively.

The factors correlational matrix showed a modest correlation between Factor 1 and Factors 2, 3, 4 (r = .54, .61, .57 respectively), a modest correlation between Factor 2 and Factors 1, 3, 4 (r = .54, .32, .50 respectively), a modest correlation between Factor 3 and Factors 1, 2, 4 (r = .57, .50, .41 respectively); while Factor 5 showed no correlation with other factors. The rotated pattern matrix (regression coefficients of the factor model equation), structure loading matrix (correlations between factors and variables), and correlation matrix between factors are presented in Table 8.

Discussion

The questionnaire appears to be a valid method to identify a pattern of hearing related deficits and several fundamental elements. Additionally, it appears to capture potential interactions among the variables based on the ICF concepts despite the presence of weak or non-significant correlations of some ICF CSHL single-item scales with the standardized validating measures. The important concept to recognize in this analysis is that the ICF categories are hierarchically organized, which makes the qualitative nature of factors linked either directly or indirectly. Therefore, because of this hierarchical organization, it is not surprising that there are variations in size of the correlations between ICF CSHL with some being quite large and others relatively small in comparison to the single-item scales. In this study, we used a horizontal and vertical approach to assess each category. For example, when patients reported some degree of perceived hearing disability in clinical practice, pure tone audiometry, self-report questionnaires and/or speech audiometry were used to verify patients' complaints. Similarly, when patients complained of bothersome sensations related to HL, specific-condition self-report questionnaires were used to verify patients' complaints accompanied with other objective measures. Furthermore, to measure the non-audiologic factors such as visual, psychosocial-cognitive, and their environmental determinants such assessment may require additional referral or testing. This method was reflected on some observed strong, weak, and non-significant correlations which are equally important to discuss.

The observed strong or moderate correlations were found between ICF scales of ear symptoms/signs (HL, perceived hearing impairment, tinnitus, and dizziness) and ICF scale related emotion function, and their representative outcome measures. In terms of HL, it is well accepted that the magnitude of the HL can impact the following categories related the hearing functions [Sound detection (b2300), Sound discrimination (b2301), Localization of sound source (b2302), Lateralization of sound (b2303), Speech discrimination (b2304)] as well as the categories related skills [Listening (d115), Communication (d310), Conversation (d350), Using Communication Techniques (d360)]. This granular information was reflected in the strong or moderate correlation between ICF-Q6 (What is the extent to which you can understand the speech of significant others in noise or over distance?) and the clinical hearing tests (PTA, BKB-SIN, and SSQ). In terms of perceived hearing impairment, tinnitus, dizziness, and emotion, a strong or moderate

Table 8: The five-factor solution of the ICF CSHL-based questionnaire obtained by principal component analyses with the Promax rotation method

Items Summary		Rotated Pattern Matrix (Regression Coefficients of Factor Model Equation)					Rotated Structure Matrix (Inter-correlation)				
Body Structure		F 1	F 2	F 3	F 4	F5	F 1	F 2	F 3	F 4	F5
PTA: Average of hearing thresholds of better ear		.20	-.04	.75	.07	-.06	.68	.34	.90	.48	-.06
PTA: Average of hearing thresholds of worst ear		.22	-.05	.78	-.01	.02	.67	.31	.90	.40	.03
Short descriptions of ICF CSHL-based questionnaire in Body Function Domain											
Q1	Temperament & Personality function	-.10	.93	.03	-.12	-.25	.32	.81	.22	.33	-.21
Q2	Attention function	-.07	.63	.14	.11	.17	.44	.70	.34	.42	.17
Q3	Working memory function	.18	.40	.05	.16	.20	.54	.60	.35	.45	.25
Q4	Emotional function	.05	.60	-.14	.19	-.06	.40	.67	.16	.47	-.06
Q5	Seeing function	.06	.10	-.16	.71	.14	.47	.47	.22	.73	.05
Q6	Hearing function	.92	.05	.07	-.18	.05	.90	.48	.58	.40	.16
Q7	Tinnitus sensation	.43	-.03	.01	-.05	.02	.40	.17	.24	.18	.06
Q8	Dizziness and imbalance	-.10	.04	.15	.75	.07	.43	.40	.40	.75	-.03
Short descriptions of ICF CSHL-based questionnaire in Activities Limitations and Participation Restrictions Domain											
Q9	Listening	.94	.06	-.10	-.10	-.27	.83	.48	.46	.47	-.17
Q10	Communication	.70	-.01	.07	.16	-.13	.81	.46	.56	.60	-.09
Q11	Conversation	.59	.27	-.03	.02	.02	.70	.60	.41	.48	.08
Q12	Communication techniques	.68	-.25	-.05	.31	.06	.70	.26	.41	.55	.07
Q13	Family relationships	.17	.57	-.08	-.13	.21	.37	.57	.14	.20	.26
Q14	Socializing	-.05	.55	.03	.18	-.26	.34	.62	.25	.48	-.27
Short descriptions of ICF CSHL-based questionnaire Items in Environmental Domain											
Q15	Hearing technology	-.16	.05	.81	-.04	.16	.36	.22	.72	.21	.14
Q16	Sound (noise) intensity	-.46	-.12	-.15	-.00	-.17	-.64	-.43	-.47	-.37	-.22
Q17	Support from family	-.04	-.03	.06	.08	.20	.04	.00	.06	.03	.20

correlation was related to the content of each outcome measure. Usually, psychosocial or cognitive (e.g., attention) or environmental elements are substantially added to the subjective outcome measures to indicate the severity of health problem and to monitor changes of physical and functional-related health problem as in SQQ, DHI, TFI, and GDS outcome measures. This was reflected by the strong correlations between ICF-Q4 (What is the extent to which you feel unhappy or depressed?) and GDS, between ICF-Q7 (What is the extent to which you have ringing in your ears?) and TFI, and between ICF-Q8 (What is the extent to which you feel dizzy or imbalanced?) and DHI. Further, it is well accepted that there is an interchange relationship (cause-effects) between the psychosocial and cognitive functions, thus, collectively categorized under the mental function chapter in the ICF. This along with the EFA model supports our argument in the discussion section that there is no reason to think that the psychosocial and cognitive difficulties may differ between the three conditions (HL, tinnitus, and dizziness) and that stratifying effects can make measuring treatment outcomes of HL easier to achieve.

The observed weak or non-significant correlations can also be interpreted in the light of the EFA model. The <u>first</u> weak correlation was found between ICF-Q1 (What is the extent to which your personality or mood distinguish you from others?) and BFPI that measures the five dimensions of personality. Given that personality traits are etiologically heterogeneous and that the BFPI measure is well defined/detailed as compared to ICF-Q1, weak correlations would be expected. Interestingly, the direction and size of the correlations between ICF-Q1 and BFPI measure highlighted a specific pattern of personality: high on neuroticism, low on agreeableness, low on conscientiousness, and low on extraversion. Individuals with such a pattern are more likely than average to be moody and to experience a wide range of emotional liability and temperamental sensitivity to negative stimuli such as anxiety, depressed mood, and loneliness (Goldberg, 1993; Klein, et al., 2011). Also, they are more susceptible to cognitive decline and may be in the preclinical phase of Alzheimer Disease (Wettstein, et al., 2017; Terracciano, et al., 2017). This may explain why personality and temperament function (ICF-Q1) was highly inter-correlated with emotion (ICF-Q4) and cognitive (ICF-Q2, ICF-Q3) functions (see Factor 2, Table 8). Individuals with such a pattern, are more likely to report social (ICF-Q13 and ICF-Q14), communication difficulties (ICF-Q9 through ICF-Q11), sensory or perceptual impairments (ICF-Q5, ICF-Q6, ICF-Q8), and somewhat abnormal auditory behavior toward noise distraction (ICF-Q16). However, the structure of Factor 2, reminded us of a connection between the mild impact of HL and dementia-like symptoms that encompasses all these problems, as estimated from the size of the correlation coefficient of the hearing sensitivity level. In support of our findings, these possible connections were captured by the ICF Core Sets for Depression (https://www.icf-research-branch.org/icf-core-sets-projects2/mental-health/icf-core-set-for-depression) and by the clinical framework for assessing the patient presenting with altered hearing and cognitive impairment (Hardy, et al., 2016). In Hardy's et al. paper, one of the associated features that may play a role in some syndromes with peripheral or subcortical hearing impairment and dementia was the vestibulopathy and vertigo/dizziness. Those disorders are almost associated with a slight, minimal or normal audiogram, dizziness/imbalance, a heavy burden of psycho-cognitive difficulties, and abnormal behavior to sound. The role of dizziness (ICF-Q8) was much more obvious in Factor 2 than the HL (as estimated from the loading coefficient). Table 5 provided additional support Factor 2.

The <u>second</u> weak correlations were found between ICF-Q2 (What is the extent to which you can maintain your focus for a period of time, or on two or more things at the same time?), ICF-Q3 (What is the extent to which you can remember things and recall new information?), and cognitive measures including: MoCA (Montréal cognitive assessment), DSB-V (working memory via visual modality), and BTA (divided attention) tests. We compare ICF-Q2 and ICF-Q3 with total scores only because the MoCA test was selected to measure the global cognitive ability and not specific cognitive function. Given the broader scope of the MoCA measure, lower correlations would be expected with ICF-Q2 (r = -0.17). In the MoCA test, the working memory domain accounts for 5 points, while attention and working memory account for 13 points, which is equal to 43.3% of total score. The incremental increase in the magnitude of correlation (r = -0.25) suggests that additional cognitive abilities in MoCA domains were negatively impacted. Regarding DSB test, the correlation between ICF-Q2 and DSB found to be better (r = -0.30) than the correlation between ICF-Q3 and DSB (r = -0.21). This finding has two possible interpretations. First, is that the DSB is not a pure memory test, but rather a test for an intertwined relationship between attention and working memory (e.g., higher DSB scores indicate excellent attention and good working memory) as suggested by Groth-Marnat and Baker (2003). Another possible explanation that older adults who perform worse on demanding working-memory tasks requiring cognitive-control show the greatest bias toward negative information about their working memory (Mather & Knight, 2005). Regarding the BTA (divided attention) test, the correlation between and ICF-Q2/ICF-Q3 and BTA test was found to be steady and slightly better than the DSB (r = 0.34 and r = -0.32 respectively). This finding is consistent with studies that have reported older adults engaged in divided-attention tasks display no positivity bias towards information (Wilson, et al., 2004; Yaffe, et al., 1999), are more prone to have neuropsychiatric conditions that are characterized by attentional impairment (Schretlena, et al,. 1996) or to have two levels of chronic conditions (Rook, et al.,2007).

An alternative explanation for lower correlations among ICF-Q2, ICF-Q3 and the three cognitive measures is related to the difference between objective and subjective measures and to the intertwined relationship between cognitive and psychosocial problems as in many multi-items subjective measures (Fiske, et al., 2009). For example, in many multi-items subjective measures, cognitive impairment and dementia have been examined in relation to well-defined episodes of psychosocial problems. Given that the ICF-Q2 or ICF-Q3 is a subjective single-item measure, a lower correlation would be expected. The association between greater psychosocial problems and poorer cognitive functioning as in Factor 2 does support this interpretation.

The third low correlations were found between the ICF-Q16 (If you think about your environment, how you would rate the level of background noise during listening-conversation activities?) and ANL test. One would expect that the low correlation (*r*= .30) was observed because the acceptance of background noise intensity may differ between environments. Here, we argue it does not. Our argument is based on a study that reported a non-significant correlation between ANL test and subjective multiple-item measure based on preference for background sound and the listeners' preference for background sound (Freyaldenhoven, et al., 2006). Despite the correlation size, our single-item scale performed better than the in assessing ANL than the method used in Freyaldenhoven, et al., study. The better performance in our study is related to the hierarchical structure of the ICF and ICF terminology as previously discussed. For example, according to the ICF, (e250) Sound category has two further levels/ taxonomies: the Sound intensity (e2500) and Sound quality (e2501) which is differing from the levels/taxonomies of Conversation activity (d350): the Conversing with one person (d3503) and Conversing with many people (d3504). It is well known that there is a relationship between hearing aids and ability to accept a level of background intensities (Freyaldenhoven, 2007). In light of EFA model, the interaction between the magnitude of HL and the extreme barrier of background intensities level is the key factor that induces poorer auditory impairment/difficulty (ICF-Q6, ICF-Q9 through ICF-Q12) as seen Factor 1. Poorer auditory impairment/difficulty can be explained by 1) direct effects of two indicators on auditory limitations, 2) by indirect effect via psycho-cognitive problems associated with HL or with other sensory limitations, and 3) by inadequate hearing aid input due to the quality of fit or hearing aids. More importantly, despite the poorer impairment/difficulty, personality (ICF-Q1), family relationship (ICF-Q13), and participation in the social event (IC-Q14) seem to be less obvious. This indicates the important role of these items in preventing social isolation and dementia. By contrast, when background intensities level was not an extreme barrier the relationship between HL and hearing aid is stronger as in Factor 3. The residual auditory impairment/ difficulty in Factor 3 can be judged in several ways: 1) inadequate hearing aid input due to quality of fit or hearing aids, 2) magnitude of HL or hearing disability before hearing aids fitting, 3) co-morbidity with dizziness, and 4) barrier of background intensities level in some circumstances. Understanding all the possible interactions in an integrated method would improve our ability to evaluate and treat patients at risk of developing lower auditory capacity and greater hearing disability at initial diagnosis, before and after the hearing aids fitting. Further, consideration of such problems helps clinicians to overcome the fragmentation of care and to improve inter-professional collaboration across settings.

More importantly, in our previous study, we empirically investigated the relationship between hearing disability and social isolation using our set of measurement instruments (Al fakir, doctoral dissertation, 2016). A structured equation modeling showed a close relationship between SSQ and BKB-SIN and total scores of these measures including, ANL (acceptance noise level), DHI, TFI, and BTA. This relationship is independent of cognitive measures related working memory and has become dependent when mild cognitive decline, as measured by MoCA test, and depressive symptomatology, as measured by GDS (Geriatric depression scale) were combined. Also, Al fakir found that the relationship between ANL and DHI had positive and negative aspect and measured visual acuity was not a significant predictor. This is almost consistent with the EFA model, except for the visual acuity at a distance as measured by the Snellen chart, which found to be a non-significate predictor. The authors attributed this difference to two reasons. The first reason was due to participants' characteristics, in which the majority have had corrected vision and variation in actual visual acuity performance at a distance among groups was absent (see Table 1 and 5). The second reason may be related to impaired visual sensory perception in patients with dizziness, dementia, or visual dysfunction (e.g., Glaucoma) even with corrected vision. In support to our findings, these possible connections were captured by the international works related vestibular, dizziness, and balance (Grill, et al., 2012).

The fourth low correlation was found between the RAS (Family relationship assessment) total score and ICF-Q13 (What is the extent to which you have difficulty maintaining family relationships?). Due to the heterogeneity of living arrangement in our sample size (see Table 1) and significant correlation with LSNS-12 (Lubben Social Network Scale-Revised) and social subscale of the DJG-LSIS (De Jong Gierveld Loneliness and Social Isolation Scale) tests, this low correlation would be somewhat expected. Maintaining family relationships is crucial for participation in conversations, attendance at social events, and reducing negative consequences of HL and subsequent impairments. Based on Hickson and Scarini (2007) and Grenness, et al. (2016) papers, the family relationship may classified as a category within the activity limitations/participation restrictions domain when information directly obtained from hearing-impaired person or may classify as a category within the environmental factors when information obtained from the significant others (the third-party disability concept). Third-party disability is referred to the impaired functioning of family and friends due to the health condition of their significant other (WHO, ICF, 2001). In our study, we have 86 participants who are living with their significate other (spouse) and both have participated in data collection. Subsequently, the correlation between the ICF-Q13 and BKB-SIN and SSQ could be related to both exchange pathways (i.e., the respondents may interpret the single-item in a more personalized manner in relation to their or significant other health problems).

The fifth low correlation was found between ICF-Q17 (If you think about your environment, how you would rate the support you received from close family members during listening-conversation activities?) and the LSNS-12 (Lubben Social Network Scale-Revised) and social subscale of the DJG-LSIS (De Jong Gierveld Loneliness and Social Isolation Scale) measures. We suggest that respondents may interpret the single item in a more personalized manner. For example, some may weigh the importance of certain types of positive social versus negative affect situations of support differently; others may consider scenarios that are explicitly covered by both measures (LSNS-12 or DJG-LSIS) based on the level of chronic conditions they have. This interpretation is consistent with the EFA model in which observed the loading of LSNS-12 was not obvious across factors as compared to the loading of DJG-LSIS total score in Factor 4 and Factor 2. Consequently, a correlation between LSNS-12 and BKB-SIN or SSQ was not significant. Certainly, lack of correlation does not imply lack of social support effect, but it may imply that the DJG-LSIS measure did much better than the LSNS-12 measure. These findings are consistent with Grenness, et al. (2016) case example.

Finally, age and gender correlations with HL are remarkably consistent across the literature. In our study, we found a significant correlation between gender and PTA, in which females could be more sensitive detecting changes in their hearing as compared to males (Kricos 2000). Unlike Banh, et al., (2012) findings, however, a correlation between age and SSQ was lacking. Certainly, lack of correlation does not imply the absence of age effect, but it may imply the mediation/moderation effects of functional problems measured by the ICF items more than the age effect on SSQ.

To our knowledge, this is the first study that creates an ICF CSHL-based questionnaire to measure the presence and magnitude of selected factors contained in the CSHL. Measuring the ICF CSHL using the structured questionnaire format is a feasible and reliable method when completed from patient's perspective and regardless of their cognitive status. This is consistent with Beauchet, et al. (2014) who found that cognitive impairment does not influence older adult's ability to evaluate their health and functional status. Further, the scores of the ICF CSHL-based questionnaire as compared to the corresponding instrument measurements as seen in Table 4 and 5 provided further clinical validity and suggest the potential clinical use of the questionnaire. The ICF CSHL-based questionnaire can be used as a template to screen for functioning and disability aspects before hearing evaluation/consultation. Additionally, it could be used to monitor changes over time after initial ear diagnosis, and to tailor rehabilitative treatment to the individual. Furthermore, this questionnaire could be used to compare a patient's reported functional status reflected by their responses to the ICF CSHL questions with other clinically accepted hearing related outcome measures.

The present study, like all studies, was not without limitations. First, our study was completed in a sample of non-clinical older adults, fairly well educated, and of a higher social, economic status. Second, only 23 categories were used in this study; consequently, a potential contribution of uncovered categories requires an additional study. Third, the argumentative process of questions to operationalize the data model was guided by feasibility rather than the efficiency and granularity. The argumentative process of questions that weighs efficiency and granularity seems to be the next important step to enrich the current version of our data model.

Conclusion

Chronic hearing disability is a complex condition. Identifying which factors may confound each person's disability is a challenge and requires significant effort for clinicians to manage. The ICF-based questionnaire presented here can be one tool that clinicians may be able to use in the future to assist in this process. By using it, we shift our attention from the biomedical perspective to a biopsychosocial perspective, which is essential in considering the whole patient. In addition to the magnitude of HL, tinnitus, and psychosocial-cognitive impact as common factors that can modulate hearing disability, the ICF CHSL-based questionnaire captures the role of dizziness and imbalance sensations on the level of hearing disability. Moreover, by including questions that reflect personal and environmental factors helps to highlight how these areas affect a patient's activity limitations and participation restrictions in daily life. Understanding these possible interactions in our patients should improve our ability to evaluate and treat them holistically at the initial diagnosis and before the hearing aid fitting. We suggest that the ICF-based questionnaire is sufficient to measure functioning and disability in older adults, to identify common factors and fundamental elements, and to capture potential interactions based on the ICF concept. Furthermore, this ICF-CHSL based questionnaire may enhance the delivery of audiological services, treatment, and rehabilitation in the future. Additional research is required, to determine the dual impact of HL and dizziness and balance-based limitations on hearing aid outcomes.

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Appendix "A"

Demographic information

Sex: [ ] Female [ ] Male **Age: …………………**

Years of formal education:
[ ] High school (12 years) [ ] B.S (14 - 16 years) [ ] Professional degree=MS, Ph.D (>16 years)

Current marital status
[ ] Never married [ ] Married [ ] Divorced [ ] Widowed

Do you live alone or with other people?
[ ] Live with spouse
[ ] Live with other relatives or friends
[ ] Live with other unrelated individuals (paid help etc.)
[ ] Live alone

Current occupation
[ ] Retired
[ ] Paid employment
[ ] Self-employed
[ ] Unemployed (health reason)
[ ] Unemployed (other reason)
[ ] Non-paid work, such as volunteer/charity

Medical diagnosis of existing main health conditions:
[ ] No medical condition exists
[ ] Yes there is medical condition exists Specify……………………………………………………………………………..
………..

Please check one of these options:

1. I have no hearing aid/s [ ]

I have hearing aid/s: I use one hearing aid (left ear) [ ] I use one hearing aid (right ear) [ ]

If you have been using hearing aid/s, for how long?

_______ Years _______ Months ________weeks

Hours: [ ] Less than 1 hour a day [ ] 1 to 4 hours a day [ ] 4 to 8 hours a day [ ] More than 8 hours a day

If you have been using hearing aids, do your hearing aids help you understand the people you speak with most frequently?

Not at all Extremely
0 1 2 3 4 5 6 7 8 9 10

If you have been using hearing aid/s, do your hearing aids reduce the number of times you have to ask people to repeat?

Not at all Extremely
0 1 2 3 4 5 6 7 8 9 10

If you have been using hearing aid/s, do you think you're hearing aids working appropriately?

Not at all Extremely
0 1 2 3 4 5 6 7 8 9 10