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Validation of a Computer-Administered Version of the Digits-in-Noise Test for Hearing Screening in the United States

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Abstract

Background—The sooner people receive treatment for hearing loss, the quicker they are able to recognize speech and to master hearing aid technology. Unfortunately, a majority of people with hearing loss wait until their impairments have progressed from moderate to severe levels before seeking auditory rehabilitation. In order to increase the number of individuals with hearing loss who pursue and receive auditory rehabilitation, it is necessary to improve methods for identifying and informing these people via widely accessible hearing screening procedures. Screening for hearing loss is the first in a chain of events that must take place in order to increase the number of patients who enter the hearing healthcare system. New methods for hearing screening should be readily accessible through a common medium (e.g, telephone or computer) and should be relatively easy and quick for people to self-administer.

Purpose—The purpose of this study was to assess a digits-in-noise (DIN) hearing screening test that was delivered via personal computer.

Research Design—Participants completed the Hearing Handicap Inventory for Adults (HHIA) questionnaire, audiometric testing in a sound booth, and computerized DIN testing. During the DIN test, sequences of 3 spoken digits were presented in noise via headphones at varying signal-to-noise ratios. Participants entered each three-digit sequence they heard using an on-screen keypad.

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Declaration of Interest

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Study Sample—Forty adults (16 females, 24 males) participated in the study, 20 of whom had normal hearing and 20 with hearing loss (pure-tone average [PTA] thresholds for 0.5, 1, 2, and 4 kHz >25 dB HL).

Data Collection and Analysis—DIN signal-to-noise (SNR) and PTA data were analyzed and compared for each ear tested. Receiver operating characteristic (ROC) curves based on these data were plotted. A measure of overall accuracy of a screening test is the area under the receiver operating characteristic curve (AUC). This measures the average true positive rate across false positives at varying DIN SNR cut-offs. Larger values of the AUC indicate, on average, more accurate screening tests. HHIA responses were analyzed and compared to PTA and DIN SNR results using Pearson correlation statistics.

Results—HHIA scores were positively correlated with audiometric PTA and DIN SNR results ($p < 0.001$ for all correlations). For a hearing loss criterion of one or more frequencies from 0.25 to 8 kHz > 25 dB HL, the area under the receiver operating characteristic curve (AUC) for the DIN test was 0.95. When a criterion of hearing loss was set at one or more frequencies from 0.25 to 8 kHz > 20 dB HL, the AUC for the DIN test was 0.96.

Conclusions—The computer version of the DIN test demonstrated excellent sensitivity and specificity for our sample of 40 participants. AUC results (0.95) suggest that this DIN test administered via computer should be very useful for adult hearing screening.

Keywords

hearing screening; hearing test; digits-in-noise; computer-administered; assessment

Introduction

Hearing loss (HL) is one of the most common health conditions affecting older adults. According to the U.S. National Institute on Deafness and Other Communication Disorders (NIDCD), one in three individuals older than 60 years of age and one in two older than 85 years of age have HL (<http://www.nidcd.nih.gov/health/hearing/Pages/older.aspx>). Also, HL and tinnitus are the two most prevalent service-connected disabilities in the U.S. Veterans Health Administration (VHA). This is true for the entire population of U.S. military Veterans, including those who served most recently (Veterans Benefits Administration, 2014).

The consequences of HL are familiar to millions of patients and the clinicians who work with them. Problems associated with HL include communication difficulties (especially understanding conversations when background noise is present), tinnitus, and hyperacusis or loudness recruitment. Patients who experience these symptoms often feel isolated, frustrated, anxious or depressed, which results in reduced quality of life (Monzani et al., 2008; Canton & Williams, 2012; Ciorba et al. 2012, Mondelli & Souza, 2012; Gopinath et al. 2012). A positive correlation between hearing loss and functional/cognitive decline has also been reported (Uhlmann et al., 1989; LaForge et al., 1992; Gates et al., 1996; Kalluri & Humes, 2012; Lin, 2012; Tun et al., 2012). Although studies have shown that auditory rehabilitation (including hearing aids) can improve these conditions associated with hearing loss (Mohlman, 2009; Boi et al., 2012), less than 20% of adults who would benefit from

such treatment seek help for their condition (Gates et al, 1990; NIDCD: <http://www.nidcd.nih.gov/health/statistics/Pages/quick.aspx>). Hutchison et al. (2012) concluded that the sooner people receive treatment for hearing loss, the quicker they are able to recognize speech and to master hearing aid technology. Unfortunately, Davis et al. (2007) reported that a majority of people with hearing loss wait until their impairments have progressed from moderate to severe levels before seeking auditory rehabilitation. Davis et al. stated that hearing aid candidates who were identified early had greater benefit through additional years of hearing aid use and better adaptation to use compared to those of the same age and hearing impairment who were fitted with hearing aids later.

In order to increase the number of individuals with hearing loss who pursue and receive auditory rehabilitation, it is necessary to improve methods for identifying and informing these people via widely accessible hearing screening procedures (Donahue et al, 2010). Screening for hearing loss is the first in a chain of events that must take place in order to increase the number of patients who enter the hearing healthcare system. New methods for hearing screening should be readily accessible through a common medium (e.g, telephone or computer) and should be relatively easy and quick for people to self-administer.

Using Digits-in-Noise to Screen Hearing

Smits et al. (2004) developed a hearing screening test that can be delivered via telephone in order to allow access by large numbers of individuals in a population. Smits & Houtgast (2005) asked callers to identify series of spoken 3-digit sequences presented in background noise at varying signal-to-noise ratios (with fixed-level speech-shaped noise). After listening to each series of 3 digits, participants entered the digits on their telephone keypad. At the end of the call, participants were informed that their performance was “Good,” “Marginal” or “Poor” based on speech reception in noise thresholds (SRT_n) calculated for all of the 3-digit sequences. Participants with ratings of “Marginal” or “Poor” were advised to visit a hearing specialist for further evaluation. In 2006, Smits et al. reported that more than 159,000 people had used the Dutch version of their test. Telephone versions of the digits-in-noise test – using region-appropriate languages – have also been implemented in England, Australia, Germany, Poland, Switzerland and France.

In 2012, Watson et al. reported their development of a U.S. version of the telephone digits-in-noise (DIN) test that uses a “Middle American” dialect. For this test, 64 triplets of one-syllable digits (chosen from 1, 2, 3, 4, 5, 6, 8 and 9) with similar psychometric-function slopes were adjusted for equal difficulty and included in the test battery. In the initial version of the test, 40 3-digit sequences were presented to each participant in order to determine the minimum number of sequences necessary for a reliable test. When Watson et al. plotted telephone DIN signal-to-noise (SNR) ratios against pure-tone average (PTA) thresholds for two different groups of participants, Pearson correlation coefficients (r) of 0.74 and 0.76 were obtained. These results are comparable to those reported for Dutch ($r = 0.72$; Smits et al., 2004), French ($r = 0.77$; Jansen et al., 2010) and Australian ($r = 0.77$; Golding et al., 2007) versions of the telephone DIN test. Applying a 20 dB HL PTA criterion for hearing loss and a SRT_n cut-off of -5.7 dB SNR, Watson et al. reported sensitivity and specificity values of 0.80 and 0.83 for their telephone version of the DIN test. The validity of that test

was confirmed in a second more extensive study conducted at three hearing clinics operated by the U.S. Department of Veterans Affairs, in which pure tone audiograms and the DIN test were obtained for over 1000 ears (Williams-Sanchez et al., 2014).

The purpose of the present study was to develop and evaluate a computer-based version of the DIN test using a modification of stimuli and parameters described by Watson et al. (2012). Specifically, we aimed to validate the accuracy and sensitivity of this computer-based DIN test for identifying individuals with hearing loss. A DIN screening test has the following advantages compared to pure tone screening tests: a) the ability to understand words in noise is more relevant to participants than pure tone testing; b) DIN testing does not require the precise calibration of pure tone assessment, so it could be used in applications including stand-alone kiosks, over the telephone, and on line.

Methods

All study protocols were approved by Institutional Review Boards at Oregon Health & Science University and Portland VA Medical Center. Informed consent was obtained from all participants prior to their participation in this study.

DIN Test Development

The computer version of the DIN test was developed by Communication Disorders Technology, Inc. (Bloomington, IN) by revising the telephone DIN test they described and assessed previously (Watson et al., 2012, Williams-Sanchez et al., 2014). A key step in the development of DIN tests is the adjustment of each recorded digit sequence to achieve uniform recognition performance. This is required because of the variation in recognition associated with different human vocalizations and also for specific samples of noise in which the digit sequences are presented. Broadband recorded stimuli equated for recognition using only the telephone bandwidths are quite unlikely to remain equally recognizable if presented via broadband earphones. For this reason, a new version of the DIN test was developed for this project by two of the authors (GRK, CSW). A subset of the 80 digit sequences originally recorded for the telephone-administered version of the test was selected for this purpose. The stimuli were chosen and adjusted for equal recognizability at a given (nominal) SNR following procedures similar to those used for the telephone version. Each of the 80 digit sequences was presented to 7 listeners at 10 different SNRs, ranging from -20 dB to -2 dB in 2-dB steps. A unique sample of noise (speech-shaped; based on the spectrum of the full set of spoken digit sequences) was paired with each digit sequence. A unique speech-shaped noise burst was used as the masker for each three-digit series to avoid the learning that has been shown to occur when a single noise sample is repeated (Coble & Robinson, 1992; Lyzenga & Smits, 2011).

Each digit sequence was presented once at each SNR, with the selection of the sequence and SNR randomized across 10 blocks of 80 trials. Stimuli were presented using Sennheiser HDA 200 circumaural headphones with the noise fixed at 75 dB SPL. Listeners were instructed to enter the digits in the order presented using a mouse to click on digits in a simulated telephone keypad displayed on a computer monitor.

Group psychometric functions were fit to each of the digit sequences and a set of 50 sequences with fairly uniform slopes and similar performance levels was selected from the set of 80, with the most extreme slopes and poorest fits excluded. A set of 11 SNR values, in 2-dB steps, was then selected for each of the digit sequences, with the 50%-correct point for each sequence set at level 8 by adjusting the level of the digit sequence. This resulted in an average SNR that ranged from approximately 2 dB at level 1 to -18 dB at level 11, and about -12 dB at the 50% point (level 8). These stimuli were incorporated into the new computer-administered version of the DIN test.

Participants and Materials for the Current Study

For this DIN evaluation study, forty adult participants were recruited from the local community. After signing the informed consent form, all volunteers completed the Mini Mental State Exam (MMSE), Hearing Handicap Inventory for Adults, audiometric testing in a sound booth, and a computer version of the DIN test. The MMSE is a 30-point questionnaire used to assess cognitive mental status (Folstein et al., 1975). It assesses orientation, attention, immediate and short-term recall, language, and the ability to follow simple verbal and written commands. A minimum MMSE score of 24 was required for participation in the study in order to identify and exclude participants with dementia or other forms of cognitive impairment. All participants then completed the Hearing Handicap Inventory for Adults (HHIA), a 25-item written questionnaire (Newman et al., 1990) which assesses the emotional and social consequences of auditory dysfunction. Participants also received an audiological assessment that included otoscopic examination, tympanometry, and pure tone air conduction (at octave frequencies from 0.25 to 8 kHz) and bone conduction threshold testing (at octave frequencies from 0.25 to 4 kHz) in a clinical sound booth. Following the audiometric evaluation, participants were seated in a quiet room and instructed by an audiologist (JV) about how to take the DIN test using Sennheiser HDA 200 headphones attached to a computer (Figure 1). Participants were not informed of their previous test results prior to DIN testing.

DIN Testing

For this study, the computer system's output via headphones was set to match a 75 dB SPL calibration sound included in the DIN program. During the test, a sequence of three digits was presented to the subject's right ear, then the participant entered the three digits sequentially on a telephone keypad that appeared on the computer screen (see Figure 2). A total of thirty three-digit sequences were presented to the subject's right ear. The level of the digit sequences was varied using an adaptive algorithm, according to which the speech level (and the SNR) was reduced by 2.0 dB following each correct response and increased by 2.0 dB following each incorrect response. All three digits had to be identified in their correct order for a response to be considered correct. After right ear testing was completed, the left ear was tested with a different series of 30 three-digit sequences in noise, following the same adaptive procedure.

At the conclusion of testing both ears, a results page appeared on the computer screen (see Figure 2). Text on the screen gave one of two possible outcomes for each ear tested: 1) "Your recognition score for your [right/left] ear is within the normal range," or 2) "Your

recognition score for your [right/left] ear is below the normal range.” Based on preliminary results from this study, a SNR of -8.5 dB was chosen as the cut point for the “normal range” of hearing. Participants who were below the normal range for one or both ears received the following on-screen message: “Because your recognition score is below the normal range in one or both ears, you should get a complete hearing test from an audiologist or physician as soon as possible.” Audiology/health care contact information for Veteran and non-Veteran participants was also included at the bottom of this screen (see Figure 2). Participants with results within the normal range for both ears received the following on-screen message at the conclusion of testing: “Although these results indicate normal hearing, this was only a screening test. If you have questions or concerns about your hearing, contact an audiologist or physician.” The audiology/health care contact information shown in Figure 2 was also presented on the screen.

Data Analysis

DIN SNR and PTA data were analyzed and compared for each ear tested. Receiver operating characteristic (ROC) curves based on these data were plotted. A measure of overall accuracy of a screening test is the area under the receiver operating characteristic curve (AUC). This measures the average true positive rate across false positives at varying DIN SNR cut-offs. Larger values of the AUC indicate, on average, more accurate screening tests. HHIA responses were analyzed and compared to PTA and DIN SNR results using Pearson correlation statistics.

Results

Table 1 shows averaged data for both the hearing loss and normal hearing groups. Participants were not assigned to a “group” at the time of testing. Instead, the determination of “normal” or “hearing loss” groups was established by post-hoc analysis. The right column of Table 1 shows the results of t-tests comparing the means of the two groups for age, PTA thresholds, DIN SNRs for each ear and HHIA scores. Twenty participants had normal hearing, defined as pure-tone average threshold (for 0.5, 1.0, 2.0 and 4.0 kHz) ≤ 25 dB and with air-bone gaps < 10 dB from 0.25 – 4 kHz. Twenty additional participants exhibited mild-to-moderate sensorineural hearing loss, defined as pure-tone average threshold (for 0.5, 1.0, 2.0 and 4.0 kHz) between 26–55 dB HL and with air-bone gaps < 10 dB from 0.25 – 4 kHz. The hearing loss group was older, and had significantly higher PTAs, SNRs and HHIA scores than the normal hearing group. The normal hearing group included 11 males and 9 females, while the loss group was comprised of 13 males and 7 females.

Figure 3 shows audiometric pure-tone averaged thresholds (for 0.5, 1, 2, and 4 kHz) plotted against signal-to-noise ratios (SNRs) obtained by the DIN test for each of the 80 ears tested. Pearson correlation coefficients (r) for this relationship are 0.86 for the right ears and 0.83 for the left ears. Figure 4 shows audiometric pure-tone averaged thresholds (for 1, 2, and 4 kHz) plotted against signal-to-noise ratios (SNRs) obtained by the DIN test for each of the 80 ears tested. Pearson correlation coefficients (r) for this relationship are 0.86 for the right ears and 0.85 for the left ears. These results indicate that the omission or inclusion of 0.5

kHz in PTA calculations does not significantly alter the relationship between PTA and DIN SNR.

Figure 5 shows Receiver Operating Characteristic (ROC) curves that were computed for two definitions of hearing loss: one or more octave frequencies from 0.25 – 8 kHz >20 dB HL (top 3 curves); or one or more octave frequencies from 0.25 – 8 kHz >25 dB HL (bottom 3 curves). These definitions of hearing loss were used for this analysis because they are more conservative and inclusive than definitions of hearing loss based on PTA thresholds. For the 20 dB criterion, area under the ROC curve (AUC) was 0.96 for both ears, 0.97 for the right ear, and 0.97 for the left ear. For the 25 dB criterion, AUC was 0.95 for both ears, 0.93 for the right ear, and 0.98 for the left ear. Results were similar for each ear analyzed separately, as well as for both ears combined.

Table 2 shows Pearson correlation comparisons between HHIA scores, PTA and DIN SNR data for all 40 participants. Mean HHIA scores were 3.2 ± 4.6 for 20 participants with normal hearing; 33.1 ± 23.1 for 20 participants with hearing loss.

Discussion

The purpose of this study was to develop and assess a computer-based version of the DIN test to be used for hearing screening in the U.S. Our ultimate goal is to make this hearing screening test widely accessible so that more people with significant hearing loss will be identified and will receive appropriate hearing health care. Yueh et al. (2010) reported that more than 50% of participants with hearing loss in their study, conducted at the Seattle Veterans Affairs hospital, pursued hearing health care after being screened by questionnaire or a combination of tone-emitting otoscope + questionnaire. The questionnaire used by Yueh et al. (2010), the Hearing Handicap Inventory for the Elderly (HHIE – Ventry & Weinstein, 1982), is very similar to the HHIA questionnaire used in the present study. Both of these questionnaires assess perceptions of hearing difficulties experienced by individuals in everyday situations. In the present study, HHIA scores correlated significantly with both DIN SNR and PTA results for each ear tested (Table 2). While correlations between HHIA/HHIE and PTA results have been reported in previous studies (Newman et al., 1997; Calviti & Pereira, 2009; Salonen et al., 2011), this is the first time that HHIA scores were compared to results of a self-administered DIN test in the same individuals. The fact that participants' perception of their hearing difficulties (as reflected by HHIA scores) correlates significantly and positively with SNR values provides additional evidence that the computer version of the DIN test is an effective method of hearing screening. Significant, positive correlations between SNR and PTA data observed in this study indicate that this computer version of the DIN test functions well as a method for hearing screening. The fact that Pearson r-values for SNR vs. PTA correlations were higher in this study ($r = 0.83$) than those reported for telephone versions of the DIN test (Smits et al., 2004; Golding et al., 2007; Jansen et al., 2010; Watson et al., 2012) probably reflects, a) superior attenuation and fidelity of the Sennheiser circumaural headphones used in this study compared to telephone receivers, and b) broader frequency range of stimuli developed for this version of the DIN. The SNR cut-off point of -8.5 dB we used to distinguish participants with normal hearing from those with hearing loss resulted in one false positive and two false negative results in our study sample.

of 40 participants. This cut-off point is lower than that used by Watson et al. (2012) for the telephone version of the DIN test (-5.7 dB), a difference that also may be explained by, a) superior attenuation and acoustic performance provided by Sennheiser headphones compared to a telephone receiver, and b) the wider spectrum of the modified DIN test used for this study.

Clinical Implications and Future Directions

Although the computer version of the DIN test appears to be an excellent hearing screening method, the procedure alone might not motivate participants to pursue additional evaluations or rehabilitative hearing health care. For example, Meyer et al. (2011) reported that only 36% of individuals who failed a telephone screening test later sought professional help for hearing impairment. Participants who accurately remembered their screening test results and/or indicated that they previously considered using hearing aids were most likely to seek hearing health care after failing the screening test.

Smits et al. (2006) reported a somewhat higher rate of subsequent hearing health care access (than that observed by Meyer et al.) for participants who took the Dutch version of the telephone DIN test. Five months after taking the test, approximately 50% of participants in the Smits et al. study who exhibited evidence of hearing loss had seen or intended to see a hearing specialist for further evaluation.

What are the factors that influence participants' decision to pursue or not to pursue hearing health care after undergoing hearing screening? 1) The country/culture in which the study was conducted might influence participants' motivation to seek medical care. 2) The type of screening method and result reporting format can affect participants' understanding of test results, which can influence their decision to seek additional health care. 3) Participants' access to health care and socioeconomic status can also affect the likelihood that they will pursue additional evaluations or treatment. According to the Health Belief Model (HBM) of Rosenstock (1966), an individual's likelihood of pursuing a health care intervention is influenced by the following six constructs:

- Perceived Susceptibility: The feeling of being vulnerable to a condition and the extent to which the individual believes he/she is at risk of acquiring the condition.
- Perceived Severity: Belief in the seriousness of the consequences incurred if a person is affected by the condition both medically (e.g. death, disability, pain) and socially (e.g. effects on family life, personal relations).
- Perceived Benefits: The belief that intervention will result in positive benefits.
- Perceived Barriers: The barriers an individual believes he/she needs to overcome in order to effectively conduct some form of intervention. This includes costs, negative side effects, social stigma, and time needed for implementation.
- Perceived Efficacy: Belief the individual has that he/she can successfully use the intervention.

- Cue to Action: A cue that prompts an individual to take action. This could be internal, such as symptoms of a health problem, or external, such as media communications, interpersonal communications, or information from healthcare providers.

The DIN test can serve as a “Cue to Action” by providing information to participants about the status of their hearing. However, to motivate individuals with hearing loss to pursue additional evaluations and treatment, more of the HBM factors need to be addressed. In addition to hearing screening, information about the consequences of hearing loss should be provided. Also, it is important to address perceived benefits vs. perceived barriers associated with hearing health care. If participants are convinced that hearing loss is a significant problem and they will benefit from evaluation and treatment, they are more likely to pursue hearing health care following a positive screening result. Therefore, a comprehensive hearing screening program – one that effectively conveys this information to participants in addition to their test results – is more likely than hearing screening alone to motivate individuals with hearing loss to pursue health care for the condition (Saunders et al., 2012).

To make computer-based hearing screening available to a large number of people, such programs should be accessible online. An internet version of the European DIN test (Smits et al., 2006) is available in five languages: Dutch, German, English, Polish and Swedish (http://hearcom.eu/prof/DiagnosingHearingLoss/SelfScreenTests/ThreeDigitTest_en.html). A U.S. version of the online DIN test should be developed and implemented. Such a program should also include supplemental information designed to motivate people with hearing loss to seek additional evaluation and rehabilitative interventions. In this we agree with Laplante-Levesque et al. (2015) who concluded that hearing screening alone is “unlikely to be enough to improve help-seeking and rehabilitation rates.”

Limitations of the Current Investigation

One limitation of the current study involves our use of HDA 200 headphones. While these headphones provided excellent attenuation and sound transmission that contributed to the accuracy of our results, it is difficult to apply these results to other computer-based applications that would not utilize similar headphones. If the ultimate goal of this research program is to make an American version of the DIN test available via the internet or other network interfaces, additional investigations should be undertaken to determine how best to deliver the test to participants who use a wide variety of sound systems. The current study was primarily focused on assessing the sensitivity/specificity of this version of the DIN test by correlating its SNR results with pure tone audiometric thresholds.

Conclusions

Screening for hearing loss is the first of a chain of events that must take place in order to increase the number of patients who enter the hearing healthcare system. The computer-based DIN test described here accurately identifies hearing loss. Future refinements should adapt this test for a variety of computer/network interfaces and sound systems. In addition to providing information about participants’ hearing sensitivity, an effective hearing health

program should also motivate patients to seek further evaluation and treatment. Such a program should be developed and implemented in the U.S.

Abbreviations

AUC	area under the receiver operating characteristic curve
dB	decibels
DIN	digits-in-noise
HBM	Health Belief Model
HHIA	Hearing Handicap Inventory for Adults
HHIE	Hearing Handicap Inventory for the Elderly
HL	hearing level or hearing loss
Hz	Hertz
MMSE	Mini Mental State Exam
NIDCD	National Institute on Deafness and Other Communication Disorders
PTA	pure-tone average
SNR	signal-to-noise ratio
SPL	sound pressure level

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Figure 1.
A research participant taking the DIN test

Figure 2.
Screens from the computer version of the DIN test

Figure 3.

Plot of audiometric pure tone average (PTA) thresholds (for 0.5, 1, 2 and 4 kHz) vs. DIN signal-to-noise ratio (SNR) thresholds for 80 ears tested

Figure 4.
Plot of audiometric pure tone average (PTA) thresholds (for 1, 2 and 4 kHz) vs. DIN signal-to-noise ratio (SNR) thresholds for 80 ears tested

Figure 5.

Receiver Operating Characteristic (ROC) curves for 2 definitions of hearing loss. Top row: pure tone thresholds > 20 dB HL; Bottom row: pure tone thresholds > 25 dB HL

Table 1

Mean PTA and DIN threshold data for both ears, and HHIA total scores (mean $\pm$ standard deviation) for participants with normal hearing and hearing loss

	Normal Hearing Group (n = 20; 11 males, 9 females)	Hearing Loss Group (n = 20; 13 males, 7 females)	p
Age (years)	39.7 $\pm$ 17.2	64.9 $\pm$ 9.2	0.0001
Pure Tone Average Threshold for 0.5, 1, 2, 4 kHz – Right Ear	8.6 $\pm$ 7.3 dB HL	40.9 $\pm$ 10.9 dB HL	0.0001
Pure Tone Average Threshold for 0.5, 1, 2, 4 kHz – Left Ear	7.9 $\pm$ 8.2 dB HL	40.5 $\pm$ 10.1 dB HL	0.0001
SNR from Digits Test – Right Ear	-10.1 $\pm$ 1.2 dB	-5.0 $\pm$ 3.3 dB	0.0001
SNR from Digits Test – Left Ear	-9.4 $\pm$ 2.3 dB	-5.3 $\pm$ 2.4 dB	0.0001
HHIA Total Score	3.2 $\pm$ 4.6	33.1 $\pm$ 23.1	0.0001

HHIA = Hearing Handicap Inventory for Adults; SNR = Signal to Noise ratio

Table 2

Pearson correlation comparisons (r values) for DIN signal-to-noise ratios (SNR) and audiometric pure tone average (PTA) thresholds vs. HHIA scores for all study participants

	HHIA – Total Score	p
Mean SNR—Right ear	0.77	0.001
Mean SNR—Left ear	0.73	0.001
PTA (0.5, 1, 2, 4 kHz) – Right ear	0.78	0.001
PTA (0.5, 1, 2, 4 kHz) – Left ear	0.73	0.001

HHIA = Hearing Handicap Inventory for Adults