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Speech recognition in noise for adults with normal hearing: age-normative performance for AzBio, BKB-SIN, and QuickSIN

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Abstract

Objective: Characterize performance for adults aged 20 to 79 years with normal hearing on tasks of AzBio, BKB-SIN, QuickSIN, and acoustic Quick Spectral Modulation Detection (QSMD) in the sound field.

Setting: Cochlear implant (CI) program.

Patients: Eighty-one adults with normal hearing and cognitive function were recruited evenly across four age groups (20–49, 50–59, 60–69, and 70–79 years).

Interventions: Subjects completed AzBio sentence recognition testing in quiet and in five signal-to-noise ratios (SNRs: +10, +5, 0, –5, –10 dB), as well as the BKB-SIN, QuickSIN, and QSMD tasks.

Main Outcome Measures: AzBio, BKB-SIN, QuickSIN, and acoustic QSMD scores were analyzed to characterize typical sound field performance in an older adult population with normal hearing.

Results: AzBio sentence recognition performance approached ceiling for sentences presented at 0 dB SNR with mean scores ranging from 3.5% at –10 dB SNR to 99% at +10 dB SNR. Mean QuickSIN SNR-50 was –0.02. Mean BKB-SIN SNR-50 was –1.31 dB. Mean acoustic QSMD score was 88%. Performance for all measures decreased with age.

Conclusion: Adults with age-normative hearing achieve ceiling-level performance for AzBio sentence recognition at SNRs used for clinical CI and/or HA testing. Thus, these tasks are not inherently contraindicated for older listeners. Older adults with normal hearing, however, demonstrated greater deficits for speech in noise compared to younger listeners—an effect most pronounced at negative SNRs. Lastly, BKB-SIN data obtained in the sound field replicated previous normative data for only the youngest age group, suggesting that new norms should be considered for older populations.

INTRODUCTION

Cochlear implants (CIs) provide significant communicative benefit to recipients with moderate-to-profound sensorineural hearing loss. While most CI users achieve open-set speech recognition, listeners continue to demonstrate speech understanding deficits in the presence of background noise. Assessment of speech recognition is the primary method of validating effectiveness of hearing interventions, including CI and hearing aids (HAs). Speech recognition is generally assessed both in quiet and in noise so as to avoid ceiling effects, to use listening conditions holding ecological validity, and to address patients' most frequently reported difficulty (1).

The Centers for Medicare and Medicaid Services (CMS) indicate the following criteria for CI candidacy: 1) bilateral moderate to profound sensorineural hearing impairment, 2) lack of benefit from hearing aids, and 3) best aided sentence recognition performance less than 40% (2). At present, these criteria do not specify the conditions and materials utilized for sentence testing. Multiple validated clinical measures of speech in noise performance exist today. The tests were developed for specific populations and vary in language level, linguistic context, presentation level, signal-to-noise ratio (SNR), and difficulty. In 1996, representatives from the American Academy of Audiology (AAA), the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS), and CI manufacturers assembled to create the Minimum Speech Test Battery (MSTB), a package of recommended speech materials and evaluation guidelines for adult CI candidates and recipients (3). In light of improving outcomes and concerns about ceiling effects, the MSTB committee revised the sentence material recommendations in 2011, suggesting use of monosyllabic words in addition to AzBio Sentences (4) in quiet and noise and Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN;(5)) test (6). Subsequent studies demonstrated the clinical value of these speech in noise measures for 1) approximating realistic listening environments, 2) assessing listeners' complaints, 3) avoiding ceiling effects, 4) and evaluating pre- and postoperative performance in populations that may not struggle in quiet (7–10).

A recent survey of current CI clinical practice indicated that 100% of responding clinics use AzBio sentences testing and 68% use of speech-in-noise testing to determine CI candidacy; however, there is no consistency in the SNRs used for assessment, as 26% of clinics reported using +10 dB, 16% used +5 dB, and the remaining 55% reported using some combination of +5 and +10 dB SNR (1). Though most CI clinics are following MSTB recommendations, there are no published age-normative data for older adults listening in noise against which we can benchmark CI users' outcomes. Without such data, it is unclear 1) that candidacy criteria based on speech in noise represent a performance deficit relative to age-matched peers and, 2) what degree of postoperative deficit CI users may experience relative to their typical hearing peers.

Clinical assessment of speech recognition in noise has implications for the increasingly older population of CI users. Studies have exhibited significant benefits for older CI recipients (e.g., (11–13)). Still, researchers and clinicians have observed an inverse correlation between postoperative speech understanding and age of implantation, independent of duration of deafness (12). It is well known that older listeners have an

inherent disadvantage for understanding speech in noise as compared to younger adults (e.g., (14–17)). Consequently, many clinicians defer speech in noise testing, even at highly positive SNRs, when evaluating older listeners for CI candidacy using the argument that even older listeners with normal hearing would score poorly in noise.

Speech recognition in older listeners with normal hearing

Accurate speech recognition in noise requires both auditory and cognitive processes. Significant research has been devoted to understanding deficits linked to age and hearing loss on suprathreshold tasks of speech in noise. Previous work suggests changes in the peripheral auditory system, as reflected on the pure tone audiogram, do not fully account for performance deficits observed in older populations with and without hearing loss. Temporal processing deficits in the central auditory system likely contribute to impaired suprathreshold speech in noise performance in older listeners (e.g., (15,18–20)). Prevalent cross-sectional research designs comparing normal hearing young adults with hearing impaired elderly adults make it difficult to tease apart age-effects independent of changes to the peripheral auditory system (21).

There are conflicting reports regarding age effects for speech in noise independent of audibility with some studies demonstrating little-to-no age effects (e.g., (22)) and others demonstrating significant age-related deficits (e.g., (15,21)). In recent years, increased attention has been devoted to evaluating effects of individual differences in cognitive functioning, specifically working memory, on speech perception (23). Findings indicate that working memory is significantly correlated with speech recognition in noise for both older and hearing impaired populations, but not for young, normal-hearing listeners (16,23). Researchers hypothesize that decrements in central auditory processing, not measured with conventional audiometry, degrade the acoustic stimulus and require allocation of compensatory mechanisms (16). Therefore, the high prevalence of age-related decline in cognitive processing, notably working memory, has significant implications for older listeners' speech recognition in noise (24).

This study employed three measures to evaluate speech recognition in noise: AzBio sentences, the Bamford-Kowal-Bench Speech-In-Noise (BKB-SIN), and the Quick Speech in Noise (QuickSIN) tests. The first two measures are commonly used to evaluate CI candidacy and track performance postoperatively (6). The QuickSIN test is another widely used speech in noise measure administered to adults with or without hearing loss. The impact of age on speech understanding in noise, independent of hearing loss, has yet to be characterized for these measures. In addition, though there are AzBio norms for young adults with normal hearing (25), age-normative data for older adults are not available. Consequently, CI users' performance cannot be compared to age-normative references across a broad age span.

Aims

The present study aimed to characterize speech recognition in noise for adults with normal hearing and cognitive function across four age groups (20–49, 50–59, 60–69, and 70–79 years) for AzBio sentences, BKB-SIN, and QuickSIN tests under the conditions consistent

with the MSTB protocol. Clinical experience assessing speech in noise preoperatively for CI candidates was used to guide the following hypotheses: 1) speech recognition will decline with age at challenging SNRs ($< +5$ dB), 2) even the oldest participants with normal hearing would perform near ceiling at all positive SNRs.

MATERIALS AND METHODS

Methods adhered to the ethical standards dictated by the Vanderbilt University institutional review board (IRB approval: 151445). Prior to experimentation, all participants provided informed, written consent. Inclusion criteria specified adults with normal hearing sensitivity and cognitive function. Participants were recruited using posted flyers, emails, telephone calls, and word-of-mouth. Participants were compensated for their time.

Subjects

The study population included 81 adults recruited across four age groups: 20 to 49 years ($n = 20$), 50 to 59 years ($n = 21$), 60 to 69 years ($n = 20$), and 70 to 79 years ($n = 20$). One additional subject for the 50- to 59-year old group had been inadvertently recruited. All subjects were native English speakers with normal hearing, defined as pure-tone thresholds ≤ 25 dB HL at octave frequencies 250 to 4000 Hz, and normal cognitive function, defined as a Mini-Mental State Exam (MMSE) score of 24 or better.

AzBio Sentence Test

The AzBio corpus consists of thirty-three equivalent lists containing twenty sentences spoken by two male and two female talkers (26). AzBio sentence scoring is expressed as the percentage of correct words repeated by the subject. Lists were played in quiet and in the presence of twenty-talker babble at five SNRs ($+10$, $+5$, 0 , -5 , and -10 dB); two lists were administered per condition. Listeners were instructed to repeat each sentence and encouraged to guess when unsure. SNR condition order was counterbalanced using a Latin square technique, and the list order was randomized across listeners. The following represents an AzBio sentence example: “She always wanted to be a ballerina” (26).

QuickSIN Test

The QuickSIN test evaluates speech in noise performance using sentences spoken by a female talker in the presence of four-talker babble. The measure contains twelve lists composed of six Institute of Electrical and Electronics Engineers (IEEE) sentences, which were designed to limit contextual cues and drive reliance on acoustic cues (27,28). The target sentences are presented at a fixed level and the babble level increases in 5-dB steps, thereby decreasing SNR in 5-dB increments between sentences ($+25$ to 0 dB SNR). Scoring is based on the correct repetition of five key words per sentence. Scores are clinically reported as SNR loss, the difference (in dB) between a listener’s performance and that of normal-hearing adult controls. The value of SNR loss is calculated by subtracting the total correct key words from 25.5. In the present study, scores were also reported as SNR-50, the SNR required for 50% recognition. SNR-50 was calculated by subtracted the number of correct key words from 27.5 (27). Four QuickSIN sentence lists were administered at two target speaker presentation levels, 60 and 70 dBA in the sound field. The present study

aimed to administer the speech-in-noise protocols consistent with standard MSTB clinical recommendations. To meet this aim, QuickSIN was presented at 60 dBA, adherent to CI evaluation clinical practices. The test was also presented at 70 dBA to comply with the test developer's guidelines for listeners with pure-tone average (PTA) less than 45 dB HL (27). The list and presentation level order were selected pseudo-randomly and varied between patients. The following represents a QuickSIN sentence example (key words underlined): “A cruise in warm waters in a sleek yacht is fun” (27).

BKB-SIN Test

The BKB-SIN test provides materials for listeners for whom the QuickSIN test is too challenging. The measure consists of eighteen list pairs comprised of up to twenty sentences spoken by a male talker in the presence of four-talker babble (5). The measure utilizes short, high-context sentences preceded by the verbal cue, “ready.” Supportive syntactic and semantic cues supplement acoustic information. Like QuickSIN, SNR varies with sentence. The first eight list pairs have an extended SNR range (+21 to −6 dB SNR) and were selected for use in the present study. The target sentence level is fixed for the first eight sentences and attenuated for the ninth and tenth sentence by 3 and 6 dB, respectively. The babble level increases in 5-dB steps for the first seven sentences and is fixed for the sentences 8–10. All twenty sentences in each list pair were presented regardless of listener performance on preceding sentences. BKB-SIN sentences were also presented at 60 dBA in the sound field, consistent with MSTB protocol. Lists are scored based on the number of correctly identified key words. Performance is reported as SNR-50 in dB calculated based on the SNR at which a listener correctly recognizes 50% of the key words. The following represents a BKB-SIN sentence example (key words underlined): “The little girl is shouting” (5).

Assessment of Spectral Resolution: Acoustic QSM

The acoustic QSM task (29) assesses spectral envelope perception by means of a method of constant stimuli using a three-interval, forced-choice procedure. Each 60-trial run consisted of three blocks of noise: two contained the same flat spectrum and a third contained a spectrally modulated noise. Spectral modulation was achieved by applying logarithmically spaced, sinusoidal modulation to the broadband carrier stimulus with a bandwidth of 125 to 5600 Hz. Six trials were presented at each of the ten modulation depths (4 to 22 dB, in 2-dB steps) with a fixed modulation frequency or rate of 1.0 cycle/octave for a total of sixty trials. This task was designed with the intent of being used for assessment of spectral resolution for use in a preoperative assessment of ear-specific CI candidacy. Because there are studies showing ears with better spectral resolution—determined using tasks of spectral modulation detection—yield significantly better bimodal benefit when combined with a CI, this acoustic QSM task was developed with the intent to identify ears with better spectral resolution to be left untreated for acoustic use in a bimodal hearing configuration (30,31).

For the acoustic QSM task, subjects were asked to report which of the three sounds was not like the others. If the subject believed that all three sounds were the same or they were unsure which one was different, they were required to guess. This measure provides a single

score, in percent correct, collapsed across modulation rate and depth (33% representing chance).

Speech Recognition Testing Procedure

Following pure-tone audiometry and MMSE administration, speech recognition testing was conducted in a sound-treated booth. Speech stimuli and competing babble were presented through a Grason-Stadler Model 61 audiometer to a single loudspeaker at zero-degrees azimuth. Prior to each test session, a Larson Davis LxT sound level meter was used to calibrate at the position of the listener's head, one meter from the loud speaker. Subjects were instructed to repeat each sentence to the best of their ability, guessing when necessary.

Analysis

AzBio and acoustic QSM data were analyzed by multiple regression using age, SNR, the interaction of age and SNR, gender, audiometric thresholds, and MMSE as regressors. The BKB-SIN and QuickSIN data were analyzed using linear regression to examine age effects, and a Pearson correlation to examine the relationship between the tests.

RESULTS

Mean AzBio scores were near 100% for quiet, +10 dB SNR, and +5 dB SNR. Mean AzBio scores for 0 dB SNR, -5 dB SNR, and -10 dB SNR were 81.83%, 34.63%, and 3.49%, respectively (See Table 1 and Figure 1). AzBio data were then analyzed by multiple regression. Using a "forced entry" method, the effect of SNR was first examined followed by the addition of age and then the interaction between the two as regressors in three separate models. The regression for the effect of SNR revealed a good fit ($R^2_{adj} = 0.959$) with a significant relationship ($F_{5,480} = 2239.9$, $p < 0.0001$). The regression was a significantly better fit when age ($R^2_{adj} = 0.969$; $F_{Change\ 1,479} = 146.3$, $p < 0.0001$) and interaction ($F_{Change\ 5,474} = 44.960$, $p < 0.0001$) were added to the model. The addition of audiometric thresholds, MMSE score, and gender to the regression did not result in a significant change in the R square value. Overall, AzBio scores were negatively related to age and positively related to SNR.

The mean BKB-SIN SNR-50 and SNR loss scores were -1.3 dB and 1.2, respectively. BKB-SIN increased (i.e. worsened) with age. Linear regression confirmed a significant effect between age and BKB-SIN SNR loss score ($p < 0.0001$) with age accounting for 27% of the variance.

Mean QuickSIN SNR-50 and SNR loss scores presented at 60 dB SPL were 1.8 and -0.2 dB, respectively. Mean QuickSIN SNR-50 and SNR loss scores presented at 70 dB SPL were 1.7 and -0.3, respectively. The difference in scores between the two presentation levels was not statistically significant ($t=0.230$, $p=0.819$). Similar to BKB-SIN, QuickSIN scores increased (worsened) with age. Linear regression confirmed a small but significant effect between age and QuickSIN SNR loss ($p = 0.001$) with age accounting for 14.7% of the variance. Lastly, BKB-SIN and QuickSIN test results showed a positive correlation ($r = 0.389$, $p < 0.0001$), as expected, given that similar speech measures are inherently correlated (e.g., (32)).

The mean acoustic QSMD score for all subjects was 88%. Similar to the results for the AzBio test, multiple regression revealed a small but significant effect of age ($R^2_{\text{adj}} = 0.175$, $F_{1,65} = 15.017$, $p < 0.0001$). When other factors such as audiometric thresholds ($F_{\text{Change } 1,64} = 0.580$, $p = 0.449$), MMSE score ($F_{\text{Change } 1,63} = 0.181$, $p = 0.672$), and gender ($F_{\text{Change } 1,63} = 0.003$, $p = 0.955$) were added to the regression, there was no additional significance afforded (i.e. no further change in R^2).

DISCUSSION

This study aimed to characterize performance for older adults with normal hearing in the sound field for the AzBio sentences, BKB-SIN, QuickSIN, and acoustic QSMD tests. The results of this study yielded four main findings: 1) Older adults with normal hearing exhibit ceiling-level performance for AzBio sentence recognition for all SNRs tested except for -5 and -10 dB SNR, 2) BKB-SIN data obtained in the sound field at 60 dBA are in agreement with previously published insert earphone norms, but only for the youngest age group—all older age groups (50+ years) performed more than one standard deviation outside the published insert earphone normative data, 3) QuickSIN data obtained in the sound field were not significantly different for 60 and 70 dBA presentations levels, and our data replicated previously published normative data for this task, and 4) there was a significant effect of age on performance for all tests.

AzBio Sentences

AzBio sentence testing revealed adult subjects across the age range performed near ceiling at SNRs used for clinical evaluation of adults with CIs and HAs (Figure 1). These findings support current clinical applications of AzBio sentence testing in noise with older adult listeners as well as the use of AzBio sentences in noise—at positive SNRs—for CI candidacy purposes. In other words, these data do not support the notion that speech in noise testing (at $+5$ or $+10$ dB SNR) is fundamentally too difficult for older listeners, nor does it support the notion that older listeners are at an inherent disadvantage for these tasks, *independent of hearing loss*. These data support current practice guidelines for the inclusion of speech in noise testing during CI candidacy evaluations and follow up (1,33). If our ultimate goal is for adults with hearing loss to reach performance of their typically hearing peers, speech in noise should be considered as their peers are scoring near 100%.

QuickSIN Test

Mean SNR-50 and SNR loss for the QuickSIN test in this study were $+1.8$ dB and -0.2 dB, respectively (See Table 1). Previous investigations of QuickSIN performance for adults with normal hearing indicated average SNR loss scores ranging from 0.0 to $+2.3$ dB (34–36). The mean QuickSIN SNR loss score amongst our subjects was -0.2 dB. The overall mean and the individual age group means fell within one standard deviation (1.25) of previously published norms (36). Our results, therefore, replicate previous findings and suggest that previously published QuickSIN age-normative data remain applicable for listeners up to 79 years of age. Furthermore, we found equivalent performance and age-related trends at 60 and 70 dBA. The MSTB recommends a presentation level of 60 dBA, which is comparable to the level of conversational speech (6). The consistent findings between presentation levels

supports this recommendation, as widespread use of 60 dBA for QuickSIN testing may offer greater ecological validity and consistency across test measures.

BKB-SIN Test

Mean SNR-50 and SNR loss for the BKB-SIN test in this study were -1.31 and 1.19 , respectively (See Table 1). Normative adult performance reported by the test developers, specified a mean SNR-50 score of -2.5 dB SNR ($n = 20$) using insert earphones and a presentation level of 83 dB SPL. Contrary to QuickSIN findings, the present population norms were more than one standard deviation poorer than published norms for the older age groups. However, the mean SNR loss score for the youngest age group (< 50 years), 0.2 dB, was consistent with the test's normative data (5). Overall, these findings are consistent with previously reported age-normative data for younger adults (< 26 years), but highlight the need for appropriate age-normative data for older listeners (50+ years).

Summary

Across all measures, a significant effect of age was noted, which covaried with hearing loss. This trend is supported by the current literature such that older listeners exhibit significant decrements in performance for challenging speech in noise conditions as compared to younger controls (14–17,37). However, these data counter a common clinical perspective that the current CI MSTB speech measures presented at $+5$ or $+10$ dB SNR are too difficult for older adults, independent of hearing loss. Further studies are needed to determine whether speech recognition in noise may also be expected to decrease in the CI and/or HA population across a similar age range.

The effect of age on the variability of scores on all three tests warrants further investigation. Established normative data for AzBio, QuickSIN, and BKB-SIN for adults with CIs of different ages will facilitate appropriate performance goals and expectations. The present analysis demonstrates the need for greater understanding of the relationship between age and hearing loss on performance and variability for adult listeners across the age spectrum.

Limitations

There are a few limitations of the current study that necessitate acknowledgement. While it was our intention to control for hearing loss, and all of our subjects met our criteria and previously published criteria for normal hearing sensitivity (38,39), small differences in audibility existed amongst our subjects. The effect of audibility was found to covary with age, meaning when audibility was added to our regression model, the change in R-value was not significant. As a result, the effects of age and small differences in hearing sensitivity could not be teased apart.

Some researchers suggest that differences in cognitive ability (i.e. working memory) contribute to poorer performance on speech recognition tasks for older adults (16,23). This study utilized a rudimentary cognitive screener (MMSE), which was likely not sensitive enough to measure subtle differences in cognitive functioning. Future research in this area should consider employing additional cognitive measures, including tasks of working memory. Lastly, additional measures of the peripheral auditory system, such as otoacoustic

emissions, may have provided further insight into differences between younger and older adult subjects. Future research should consider such measures.

CONCLUSION

Adults with normal hearing perform at ceiling on AzBio sentence recognition at SNRs used in clinical adult CI candidacy and evaluation appointments including SNRs of 0, +5 and +10 dB. We also found a significant relationship between performance in more difficult conditions and age—the latter of which covaried with audiometric thresholds. Thus, the decrease in performance seen in adults with CIs is not present in older adults with normal hearing at SNRs used for clinical testing. However, speech recognition in noise may be expected to decline in the CI population with age as demonstrated for normal-hearing listeners, though additional investigation is needed to determine the effect of age in the presence of significant hearing loss. Finally, QuickSIN age-normative data were consistent with published norms for all groups tested here, but BKB-SIN age-normative data were only consistent with published norms for the 20–49-year-old group. Thus, the age-normative data presented here may serve as a more accurate reference for older listeners. Given these findings, further research should address age-specific AzBio, BKB-SIN, and QuickSIN data in the older adult CI population in order to assess how the performance of older CI users compares to typically hearing peers (39).

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Figure 1.
Individual and mean AzBio sentence recognition as a function of signal-to-noise ratio (SNR). Error bars represent ± 1 standard deviation.

Table 1.

Mean scores for the AzBio, QuickSIN, and BKB-SIN tests are provided for all participants, as well as for each age group tested.

Age Group	Mean Age (years)	Audiometric Threshold (dB HL)		AzBio (%)					QuickSIN – SNR Loss				BKB-SIN SNR Loss	QSMD (%)
		Mean	250–8000Hz	Quiet	+10	+5	0	–5	–10	60 dB	70 dB			
20–49	23.45	2.33		99.85	99.35	98.80	90.80	51.63	9.03	–0.92	–0.92	0.24	94	
50–59	54.54	18.24		99.05	99.05	97.31	83.55	35.98	2.81	0.30	–0.05	1.18	88	
60–69	63.89	19.20		99.63	99.15	96.40	78.30	26.33	1.45	–0.51	–0.66	1.41	84	
70–79	72.13	19.50		99.05	98.38	95.03	74.58	24.53	0.73	0.19	0.57	1.91	86	
Overall	53.51	14.71		99.39	98.98	96.89	81.83	34.63	3.49	–0.23	–0.26	1.19	88	