Research Article

Noise Tolerance and Speech-in-Noise Performance under Binaural Listening in Young Normal-Hearing and Older Hearing-Impaired Adults

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Short running title: Noise Tolerance and Speech-in-Noise…

Highlights:
- Older adults showed higher (poorer) SNR-50 thresholds than young adults
- Binaural ANL was not significantly associated with SNR-50
- High-frequency hearing loss strongly predicted poor SNR-50 performance, but not ANL

ABSTRACT
Background and Aim: Age-Related Hearing Loss (ARHL) impairs speech understanding in noise. Acceptable Noise Level (ANL) reflects noise tolerance and predicts hearing-aid outcomes, while Speech-in-Noise (SIN) ability is indexed by Signal-to-Noise Ratio required for 50% correct recognition (SNR-50). Their relationship under binaural listening remains unclear. This study examined binaural ANL and SIN performance in young normal-hearing and older hearing-impaired adults to determine their association and identify audiometric predictors.
Methods: Sixty-nine adults participated: 37 young normal-hearing (18–30 years) and 32 older adults with ARHL (60–80 years). Binaural ANL was measured using Persian continuous discourse with 12-talker babble. SIN performance was assessed binaurally using a monosyllabic word test, with SNR-50 estimated by the Spearman-Kärber method. Group comparisons, correlations, and regression analyses examined age effects and audiometric predictors.

Results: Older adults showed higher most comfortable levels and ANL values, indicating reduced noise tolerance, and poorer SIN performance with higher SNR-50 and greater variability. Binaural ANL was not associated with SNR-50 in either group. In older adults, SIN performance was predicted by high-frequency thresholds and hearing loss severity, whereas ANL was not a significant predictor.
Conclusion: Under binaural conditions, noise tolerance and speech intelligibility are dissociable. In older adults, SIN ability was predicted by high-frequency hearing sensitivity and overall hearing loss severity, whereas ANL was not a significant predictor, underscoring the importance of multidimensional auditory assessment in clinical practice.
Keywords: Age-related hearing loss; speech-in-noise performance; acceptable noise level; high-frequency hearing loss

Introduction

Aging is a natural process marked by gradual bodily changes that reduce resilience at molecular and cellular levels [1]. The proportion of people aged 60 and older is expected to nearly double by 2050, increasing from 12% to 22% of the global population [2]. Among age-related challenges, Age-Related Hearing Loss (ARHL) is one of the most prevalent and impactful conditions [3]. ARHL typically affects both ears, begins in high frequencies, and involves changes in the inner ear and central auditory pathways [4]. It reduces audibility and makes following conversations in noisy environments difficult, contributing to social withdrawal, cognitive decline, and lower quality of life [5, 6]. Listening in noise becomes disproportionately challenging with age, even when hearing thresholds are similar to younger adults [7, 8]. Uptake is limited for personal and social reasons, and many report that hearing aids provide limited benefit in noisy settings [9].

Aging affects peripheral, central, and cognitive mechanisms that support auditory processing [10]. Peripherally, ARHL involves degeneration of cochlear hair cells, loss of spiral ganglion neurons, and cochlear synaptopathy, which reduce neural output and degrade temporal and spectral coding [11]. These deficits limit the fidelity of signals entering the central auditory system, especially for rapid or complex sounds. Centrally, age-related changes in the brainstem and cortex —such as altered inhibitory neurotransmission, reduced temporal synchrony, and cortical reorganization —impair binaural integration, auditory scene analysis, and speech tracking in noise [12, 13]. Cognitive capacities that support listening, including attention, working memory, and executive control, also decline with age, further exacerbating speech perception difficulties under challenging conditions [13]. This interplay helps explain why older adults often struggle disproportionately with communication in noisy environments, even when audiometric thresholds appear only moderately impaired [11]. Binaural processing improves speech perception in noise by enhancing signal clarity, providing redundant cues, and boosting recognition through central auditory integration [14]. However, age-related declines in neural synchrony and temporal processing reduce these benefits, contributing to poorer speech-in-noise (SIN) performance in older adults, even under diotic listening conditions [15, 16].

The Acceptable Noise Level (ANL) test measures how much background noise a listener can comfortably accept while following speech [17], whereas the Signal-to-Noise Ratio required for 50% correct recognition (SNR-50) test assesses the signal-to-noise ratio needed to correctly identify 50% of speech stimuli [18, 19]. ANL reflects noise tolerance and predicts hearing-aid success: lower ANLs are linked to more consistent use, while higher ANLs indicate greater difficulty adapting to amplification [20]. Age alone does not strongly affect ANL, as younger and older adults often show similar noise acceptance when tested under comparable conditions, though listening may become more effortful with age [20, 21]. Most ANL research has used monaural testing for experimental control and clinical practicality, allowing assessment of individual ear differences without binaural advantages [17, 20]. However, recent findings show that binaural listening can improve both ANL and SNR-50, which is important for understanding everyday listening in older adults [22, 23].

Despite growing evidence regarding ANL and SNR-50 individually, few studies have examined their relationship under binaural listening conditions in age-diverse populations. Most previous ANL research has used monaural paradigms for experimental control [17, 20], although everyday communication relies on binaural processing and its associated benefits for speech perception in noise [14, 22]. Consequently, monaural findings may not fully reflect real-world listening behavior, particularly in older adults with hearing loss. Examining ANL and SNR-50 together under binaural conditions may clarify whether noise tolerance is associated with speech recognition in everyday listening environments.

Accordingly, this study investigated binaural ANL and SNR-50 in older adults with hearing loss and young adults with normal hearing and examined audiometric predictors of SIN performance. It was hypothesized that older adults with hearing loss would exhibit higher ANL values and poorer SIN performance than young normal-hearing adults. In addition, binaural ANL was expected to show a limited association with SNR-50, reflecting partially independent dimensions of listening behavior under noisy conditions.

Methods

Participants

Thirty-seven young adults with normal hearing (18–30 years; 22.2±3.0 years; 32 females) and 32 older adults with hearing loss (60–80 years; 67.7±5.0 years; 9 females) participated in the study. Prior to auditory assessment, otoscopy and tympanometry were performed to confirm normal outer- and middle-ear function. Otoscopic examinations were carried out using a HEINE BETA200 LED F.O. Otoscope, and tympanometry was conducted with an AT235h middle-ear analyzer (Interacoustics, Denmark). Audiometric testing was performed in a sound-attenuated booth using a two-channel clinical audiometer (Madsen Astera, GN Otometrics/Natus, Denmark), with stimuli delivered through TDH-39 circum-aural headphones. Pure-tone audiometry was conducted to obtain air- and bone-conduction thresholds.

Audiometric results confirmed normal bilateral hearing in the younger group, defined as pure-tone thresholds ≤25 dB HL from 250 Hz to 8 kHz, with a mean Pure-Tone Average (PTA), $PTA_{0.5–4kHz}$ of 3.2±2.2 dB HL. In contrast, the older group exhibited an audiometric profile consistent with presbycusis —symmetrical, high-frequency, sloping sensorineural hearing loss —with a mean $PTA_{0.5–4kHz}$ of 29.0±12.3 dB HL. This configuration was selected because it is characteristic of age-related hearing loss and provided a relatively homogeneous sample while minimizing confounding from asymmetric or non-age-related hearing loss. Symmetry was defined as interaural threshold differences of no greater than 10 dB at corresponding frequencies. A sloping configuration was defined as progressively poorer thresholds at higher frequencies, with thresholds above 2 kHz elevated relative to low-frequency thresholds. Audiograms typically showed normal or near-normal thresholds at 250–1000 Hz and progressively elevated thresholds above 2 kHz, often exceeding 50 dB HL at 4 and 8 kHz (Figure 1). All older participants completed the Persian version of the Montreal Cognitive Assessment (MoCA-P) [24], yielding a mean score of 29.53 (SD=0.98; range=26–30), confirming normal cognitive function (≥26 cutoff) [25] and indicating that differences in ANL and SNR-50 were not attributable to cognitive impairment.

Testing procedure

Acceptable noise level test

Before testing, the speech passage and 12-talker babble noise were calibrated using the audiometer's built-in calibration and VU-meter functions. A 1000-Hz calibration tone was root mean square matched to the recorded stimuli to ensure consistent presentation levels for speech and noise. The ANL test was administered using the standardized Persian-language version, which consisted of a continuous discourse passage and a 12-talker babble noise [26]. In the audiometer's channel-routing settings, both channels were configured for binaural presentation. This configuration ensured simultaneous delivery of speech (Channel 1) and competing noise (Channel 2) to both ears through TDH-39 circumaural headphones. Before data collection, the test procedure was explained to each participant, and a practice trial was completed to ensure task comprehension.

For the ANL test, the Persian version of ANL test, previously validated and described in the literature [26], was used in the present study. The continuous discourse passage was presented binaurally at an initial level of 30 dB HL. The speech level was then increased in 5-dB steps, followed by 2-dB adjustments, until the participant indicated the level, they considered most comfortable for following the speech. This value was recorded as the Most Comfortable Level (MCL). Once the MCL was established, the speech level remained fixed, and the 12-talker babble noise was introduced binaurally at a level 30 dB below the individual's MCL. The noise intensity was adjusted in 5-dB steps, followed by 2-dB refinements. The participant chose the highest background noise level they could tolerate while still following the passage, which was recorded as the Background Noise Level (BNL). The ANL score was calculated as the difference between the MCL and BNL (ANL=MCL–BNL). To improve measurement stability, the ANL procedure was administered twice and the average score was used for analysis, consistent with the standardized Persian ANL protocol previously shown to have acceptable reliability [26].

Signal-to-noise ratio required for 50% correct recognition test

The SIN test used to estimate SNR-50 was administered using the Persian version of a standardized monosyllabic word recognition test, developed and validated by Mahdavi et al [27]. The test was presented binaurally at each participant's MCL, which had been previously determined during the ANL test. For each participant, one randomly selected half-list (25 words) was presented to both ears in the presence of 12-talker babble noise, which was also delivered binaurally. The speech level was held constant at the target MCL, while the noise intensity was systematically adjusted in 5-dB steps to achieve Signal-to-Noise Ratios (SNRs) of 0, +5, +10, +15, and +20 dB. These SNR conditions were presented in a fixed order for all participants. When necessary, brief practice trials were provided prior to testing to ensure task comprehension. To minimize potential learning or familiarity effects, different monosyllabic half-lists were used across participants, and no lists were repeated within a participant's testing session. Participants repeated each word aloud, with correct responses scored as 1 and incorrect responses scored as 0. The individual SNR-50 value —representing the SNR required for 50% correct word recognition —was calculated using the Spearman-Kärber method.

Data analyses

Descriptive statistics (mean, standard deviation, and range) were calculated for demographic and audiometric variables, as well as for MCL, BNL, ANL, and SNR-50 in both groups. The normality of distributions was assessed using the Shapiro-Wilk test. Independent-samples t-tests were applied for primary comparisons between young normal-hearing and older hearing-impaired participants on MCL, BNL, ANL, and SNR-50 measures. Factorial ANOVAs were additionally performed to examine the potential effects of gender and group×gender interactions on ANL and SNR-50 outcomes. Multiple linear and logistic regression analyses were conducted to examine audiometric predictors of SNR-50. Given the relatively modest sample size of the older adult group (n=32), regression models were restricted to a limited number of theoretically relevant predictors to minimize the risk of overfitting. Prior to regression analyses, multicollinearity among predictors was assessed using Variance Inflation Factors (VIFs), while normality and homoscedasticity of residuals were evaluated through residual inspection. No substantial violations of regression assumptions were observed. Bayesian correlation analyses were additionally performed to evaluate evidence for the null hypothesis of independence between ANL and SNR-50. Bayes factors (BF_{01}) were interpreted according to conventional guidelines for Bayesian inference. Statistical significance was set at $p<0.05$. All analyses were conducted using SPSS Statistics (version 17; IBM Corp., Armonk, NY, USA).

Results

Group differences in most comfortable level and background noise level

Older Adults with Hearing Impairment (OAHI) exhibited a higher mean MCL (mean=59.31 dB HL, SD=7.6, range=40–76 dB HL) than Young Adults with Normal Hearing (YANH) (mean=54.81 dB HL, SD=7.9, range=42–78 dB HL). For BNL, older adults demonstrated a mean of 51.84 dB HL (SD=7.7, range=36–70 dB HL), whereas younger adults showed a mean of 49.57 dB HL (SD=8.8, range=32–78 dB HL). Group comparisons indicated that MCL was significantly higher in older adults than in younger adults, $t(67)=2.30$, $p<0.03$. In contrast, no significant difference between groups was observed for BNL, $t(67)=1.10$, $p=0.26$. As illustrated in Figure 2, the distributions of BNL values overlapped substantially between the two groups.

Age-related differences in acceptable noise level

Participants in the OAHI group exhibited a higher mean ANL (M=7.40 dB HL, SD=3.6, range=0–16 dB HL) than those in the YANH group (M=5.24 dB HL, SD=3.6, range=0–10 dB HL). Examination of the score distributions indicated that ANL values in the younger group were relatively clustered, reflecting more uniform noise tolerance, whereas the older group demonstrated a wider spread of values, highlighting substantial interindividual variability (Figure 3). Group comparison revealed that older adults had higher ANL than younger adults. An independent-samples t-test confirmed that this difference was statistically significant, $t(67)=2.50$,

$p<0.015$. Notably, within the older group, some participants exhibited ANL values similar to those of the younger group, while others showed markedly higher ANL, indicating reduced tolerance for background noise.

Group differences in signal-to-noise ratio required for 50% correct recognition
Participants in the YANH group demonstrated a lower mean SNR-50 (M=2.17 dB, SD=2.1, range=−0.5 to 8.5 dB) than those in the OAHI group (M=6.50 dB, SD=3.9, range=1.5 to 20.5 dB). Examination of the score distributions indicated greater interindividual variability in the older group, with several participants requiring substantially more favorable signal-to-noise ratios to achieve 50% correct word recognition (Figure 4). Comparison between groups revealed that SNR-50 values were lower in YANH than in OAHI. An independent-samples t-test confirmed that this difference was highly statistically significant, $t(67)=5.79$, $p<0.001$.

Group differences in signal-to-noise ratio required for 50% correct recognition and noise tolerance
SIN performance, as measured by SNR-50, and ANL were first compared between YANH and OAHI. For SNR-50, a significant main effect of group was observed ($F_{(1,65)}=22.84$, $p<0.001$), with older adults exhibiting poorer SNR-50 thresholds than young adults, indicating greater difficulty understanding speech in noise. ANL also differed significantly between groups ($F_{(1,65)}=4.26$, $p<0.05$), with OAHI participants demonstrating higher ANL values, reflecting reduced tolerance for background noise. Two-way factorial ANOVAs examining the effects of group and gender revealed no significant main effects of gender ($p>0.05$) and no group×gender interactions ($p>0.05$) for either SNR-50 or ANL, indicating that age-related differences were consistent across males and females. Together, these findings demonstrate robust age-related declines in SNR-50 and noise tolerance that are independent of gender.

Interindividual variability and clinical listening profiles
Group differences in interindividual variability were examined using Levene's tests. Variance in SNR-50 was significantly greater in the OAHI group compared to the YANH group ($F_{(1,67)}=9.42$, $p<0.01$), indicating increased heterogeneity in SNR-50 among older listeners. Variance in ANL was also significantly greater in the OAHI group ($F_{(1,67)}=4.01$, $p<0.05$), although the magnitude of this difference was smaller. To further characterize this heterogeneity, participants were classified into four clinical listening profiles based on ANL (low vs. high) and SNR-50 (good vs. poor). Classifications were based on group-specific median splits. Median ANL values were 6.0 dB for both the YANH and OAHI groups, whereas median SNR-50 values were 1.5 dB for the YANH group and 5.5 dB for the OAHI group. A chi-square test revealed a significant difference in profile distributions between groups ($\chi^2(3)=18.6$, $p<0.001$), with older adults disproportionately represented in the High-ANL/Poor-SNR-50 profile, whereas younger adults were more frequently classified into profiles reflecting better SNR-50 and/or lower ANL. These results indicate that older adults not only perform more poorly on average but also exhibit substantially greater variability and clinically distinct listening profiles.

Relationship between acceptable noise level and signal-to-noise ratio required for 50% correct recognition
To determine whether tolerance for background noise contributed to SNR-50, several complementary analyses were conducted. A subgroup analysis dividing participants into low-ANL and high-ANL listeners revealed no significant main effect of ANL category on SNR-50 ($F_{(1,65)}=0.12$, $p>0.05$) and no interaction between ANL category and age group ($p>0.05$). Within-group comparisons similarly showed no significant differences in SNR-50 between low- and high-ANL listeners. Correlation analyses examining binaural SNR-50 in relation to binaural ANL also revealed no significant associations in either group (all $p>0.05$). These null findings were further supported by Bayesian correlation analyses, which provided moderate evidence in favor of the null hypothesis of independence between ANL and SNR-50 in both young and older adults ($BF_{01}\approx5$–6). Finally, an audibility-controlled analysis using residual SNR-50 values confirmed that ANL did not account for variance in SNR-50 beyond hearing sensitivity ($p=0.11$). Collectively, these converging analyses demonstrate that acceptable noise level does not meaningfully explain individual differences in SNR-50.

Audiometric predictors of signal-to-noise ratio required for 50% correct recognition
Multivariate analyses were conducted to identify audiometric factors contributing to SNR-50 in older adults. A multiple linear regression model including pure-tone average across 1–8 kHz (PTA_{1-8kHz}) and ANL as predictors accounted for a substantial proportion of variance in SNR-50 ($R^2=0.45$, $F_{(2, 29)}=11.9$, $p<0.001$). PTA_{1-8kHz}

emerged as a strong and significant positive predictor of SNR-50 (β=0.67, B=0.19, 95% CI [0.11, 0.27], p<0.001), whereas ANL did not contribute significantly to the model (β=0.06, B=0.06, 95% CI [–0.24, 0.36], p=0.69). An exploratory logistic regression analysis further showed that increasing $PTA_{1\text{–}8}$kHz significantly increased the odds of poor SNR-50, while ANL again failed to predict outcomes. These findings suggest that peripheral hearing sensitivity contributes more to SNR-50 than noise tolerance under the present study conditions.

Frequency-specific contributions to signal-to-noise ratio required for 50% correct recognition

To further refine the contribution of hearing sensitivity, frequency-specific regression analyses were performed in the older adult group. Thresholds at low frequencies (500 and 1000 Hz) showed weak and non-significant associations with SNR-50 (all p<0.001). In contrast, progressively stronger relationships were observed at higher frequencies, with thresholds at 2000 Hz showing a moderate association and thresholds at 4000 and 8000 Hz accounting for the largest proportions of variance in SNR-50. This pattern may reflect both the greater severity of hearing loss at higher frequencies and the importance of high-frequency auditory cues for speech perception. Additional analyses testing for nonlinearity indicated that linear models adequately captured the relationship between high-frequency hearing thresholds and SNR-50 (ΔR^2 not significant, p>0.05). These results demonstrate that high-frequency hearing sensitivity is the dominant audiometric contributor to SNR-50 in older adults.

Audiogram configuration and extreme-group performance

To examine whether audiogram shape influenced performance beyond overall hearing severity, older adults were classified into audiogram configuration groups. Given the modest sample size of the older adult cohort, this subgroup analyses were considered exploratory and interpreted cautiously. SNR-50 differed significantly across configurations ($F_{2,29}$=6.42, p<0.05), with participants exhibiting steeply sloping high-frequency losses showing poorer SNR-50 than those with gently sloping or relatively flat audiograms. In contrast, ANL did not differ across audiogram configurations ($F_{2,29}$=0.94, p=0.40). An extreme-group analysis comparing best and worst SNR-50 performers further revealed that poorer performance was associated with significantly worse high-frequency hearing thresholds (p<0.05), whereas ANL did not differ between groups. These findings further support the importance of high-frequency hearing sensitivity for SNR-50, independent of ANL.

Principal component analysis of audiometric thresholds

To integrate audiometric information across frequencies, a Principal Component Analysis (PCA) with Varimax rotation was performed on pure-tone thresholds. Two components were extracted: a dominant severity component reflecting overall hearing loss and a secondary configuration component reflecting audiogram slope. The severity component explained 87.9% of the total variance and showed relatively uniform positive loadings across frequencies (0.27–0.30), consistent with generalized hearing loss severity. The configuration component explained an additional 6.2% of the variance and was characterized by positive loadings at low frequencies and negative loadings at high frequencies, reflecting audiogram slope. Regression analyses using component scores showed that hearing loss severity was a strong predictor of SNR-50 (β=0.86, p<0.001), accounting for 57% of the variance in SNR-50, whereas the configuration component was not. Neither component substantially predicted ANL. This multivariate approach confirms that overall hearing loss severity, rather than audiogram configuration or noise tolerance, is the principal audiometric factor associated with SNR-50.

Secondary and control analyses

All older participants exhibited clinically symmetrical hearing loss. Correlation analyses examining subtle interaural threshold differences revealed no significant associations with either ANL or SNR-50 (p>0.05). Additional analyses showed strong positive correlations between MCL and BNL in both groups (p<0.001), while ANL remained uncorrelated with MCL or BNL (p>0.05). Finally, binaural ANL showed no significant relationship with pure-tone averages or individual frequency thresholds in either group (p>0.05), whereas binaural SNR-50 was strongly associated with hearing sensitivity only in the older adult group (p<0.001). These control analyses further support the conclusion that SNR-50 is driven by hearing sensitivity rather than by noise tolerance or related listening-level measures.

Discussion

The present study examined binaural ANL and SNR-50 in young adults with normal hearing and older adults with age-related hearing loss to clarify the relationship between noise tolerance and speech recognition under binaural listening conditions. The results demonstrated age-related differences in both ANL and SNR-50 while confirming that these measures represent largely independent aspects of listening. These findings extend previous monaural research by showing that this dissociation persists under binaural listening conditions, which more closely resemble everyday communication [28]. Participants in OAHI group exhibited significantly high MCL compared to YANH, consistent with prior reports showing elevated preferred speech levels in individuals with sensorineural hearing loss [21]. This increase in MCL likely reflects reduced audibility and degraded spectral clarity associated with high-frequency cochlear damage, which necessitate higher speech levels to achieve adequate perceptual clarity and listening comfort [29]. Central auditory changes may further contribute to elevated preferred listening levels. In contrast, BNL did not differ significantly between groups, resulting in higher ANLs in older adults. This pattern suggests that older listeners primarily regulate listening comfort by increasing speech level rather than tolerating more background noise, a strategy previously observed in elderly and hearing-impaired populations [30].
The elevated and more variable ANL observed in older adults may reflect age-related changes in auditory scene analysis and inhibitory control, leading to reduced tolerance for competing noise [13]. However, the substantial overlap in ANL distributions between groups suggests that noise tolerance is influenced by individual differences in addition to age [28].
In contrast to ANL, SNR-50 showed pronounced age-related degradation, with older adults requiring significantly more favorable signal-to-noise ratios. Although older adults demonstrated higher MCLs, SNR-50 was calculated relative to each participant's individual presentation level; therefore, group differences in absolute speech level were not expected to directly bias SNR-50 estimates. This finding aligns with extensive literature demonstrating that speech understanding in noise declines disproportionately with age, even after accounting for pure-tone hearing thresholds [8]. The large effect size and increased interindividual variability in SNR-50 among older listeners reflect heterogeneity in auditory aging, consistent with prior studies reporting wide variability in suprathreshold speech processing among individuals with similar audiograms [8]. The poorer SNR-50 observed in older adults likely reflects a convergence of peripheral and central auditory deficits. High-frequency hearing loss reduces access to critical speech cues, including the high-frequency spectral energy and formant transition patterns that encode consonant place of articulation and fricative contrasts, which are essential for accurate word recognition in noisy environments [31]. Concurrently, age-related declines in temporal envelope processing, neural synchrony, and cortical speech tracking further compromise the ability to segregate speech from competing noise [11, 13]. These mechanisms together explain why older adults often experience substantial communication difficulties in everyday noisy environments despite relatively preserved low-frequency hearing [8].
A central finding of this study is the absence of a meaningful relationship between binaural ANL and SNR-50. Across multiple analytical approaches—including subgroup comparisons, correlation analyses, audibility-controlled residual analyses, and Bayesian statistics—ANL did not predict SNR-50 in either age group. These findings suggest that ANL and SNR-50 represent largely independent dimensions of listening, reflecting subjective noise acceptance and objective speech recognition, respectively [32]. This dissociation is consistent with previous work suggesting that ANL is more closely related to listening effort and affective responses to noise than to speech intelligibility [28], although this relationship may vary across different listening tasks and populations. Clinically, individuals with greater noise tolerance may still experience poor speech recognition, and vice versa [32].
Multivariate analyses showed that SNR-50 was primarily predicted by overall hearing loss severity ($PTA_{1\text{–}8kHz}$) and high-frequency hearing sensitivity, particularly at 4 and 8 kHz, consistent with the established importance of high-frequency cues for speech perception in noise [31, 33]. In contrast, ANL did not contribute significantly to SNR-50, further supporting the functional distinction between noise tolerance and speech recognition. Low-frequency thresholds showed minimal associations with SNR-50, whereas progressively stronger relationships emerged at higher frequencies. Linear models adequately described these associations, suggesting that SIN performance declines proportionally with increasing high-frequency hearing loss.
Although audiogram configuration influenced SNR-50, with steeper high-frequency losses associated with poorer SNR-50, multivariate analyses showed that overall hearing loss severity accounted for more variance than audiogram slope. Principal component analysis further confirmed that a dominant severity component predicted SNR-50 outcomes, whereas configuration-related variance did not independently contribute. These findings are

consistent with prior reports indicating that while audiogram shape can modulate performance, severity remains the primary determinant of speech recognition in noise [34]. Importantly, older adults exhibited greater interindividual variability and were disproportionately represented in clinically unfavorable listening profiles characterized by high ANL and poor SNR-50. This heterogeneity underscores the limitations of relying on single outcome measures when assessing communication difficulties in older adults and highlights the value of combined assessments that capture both intelligibility and listening comfort [35].

The present findings have direct clinical implications for hearing assessment and rehabilitation. While ANL remains a useful predictor of hearing-aid acceptance and long-term use, it should not be interpreted as an indicator of SIN ability [20, 36, 37]. Conversely, SNR-50 provides important information about functional communication but does not capture listening comfort or noise tolerance. Using both measures together may therefore provide a more comprehensive assessment of older adults and support individualized rehabilitation planning. From a theoretical perspective, the dissociation between ANL and SNR-50 supports models of auditory aging that distinguish perceptual capacity from affective and cognitive responses to noise [32]. Noise tolerance likely reflects interactions among central auditory processing, attention, and emotional reactivity, whereas speech intelligibility depends more directly on peripheral encoding and temporal–spectral fidelity [8, 28]. Understanding this distinction is essential for developing targeted interventions that address both intelligibility and listening comfort. Several limitations should be acknowledged. The cross-sectional design precludes conclusions about longitudinal changes in noise tolerance and SIN performance with aging. Additionally, the relatively modest sample size, particularly for regression analyses within the older adult group, may limit the generalizability of the findings. Cognitive function was screened but not explicitly manipulated, and future studies incorporating more sensitive cognitive measures may further elucidate the role of attention and executive control in ANL. Finally, extending this work to aided listening conditions would help clarify how amplification interacts with binaural processing, noise tolerance, and speech intelligibility in everyday environments.

Conclusion

In summary, older adults with hearing impairment exhibited higher and more variable Acceptable Noise Level (ANL) together with poorer Signal-to-Noise Ratio required for 50% correct recognition (SNR-50) under binaural listening conditions. ANL and SNR-50 appeared to represent largely independent aspects of listening, with SNR-50 being more strongly associated with high-frequency hearing sensitivity than with ANL. However, this relationship may vary depending on task design, listening conditions, and listener population. These findings support multidimensional auditory assessment and suggest that interventions targeting speech intelligibility and listening comfort may need to be addressed independently to optimize communication outcomes in older adults with hearing loss.

Ethical Considerations

Compliance with ethical guidelines

Ethical approval was obtained from the Biomedical Research Ethics Committee at Shahid Beheshti University of Medical Sciences (IR.SBMU.RETECH.REC.1403.205), and written informed consent was obtained from all participants.

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Authors' contributions

ZN: Study design, data acquisition, statistical analysis, interpretation of the results, and drafting of the manuscript; HJ: Study design, supervision, statistical analysis, interpretation of the results, and critical revision of the manuscript; MEM: Contributed to the development and design of the speech-in-noise test materials used in this study and reviewed and approved the final manuscript; AAB: Validation of the data and statistical analyses.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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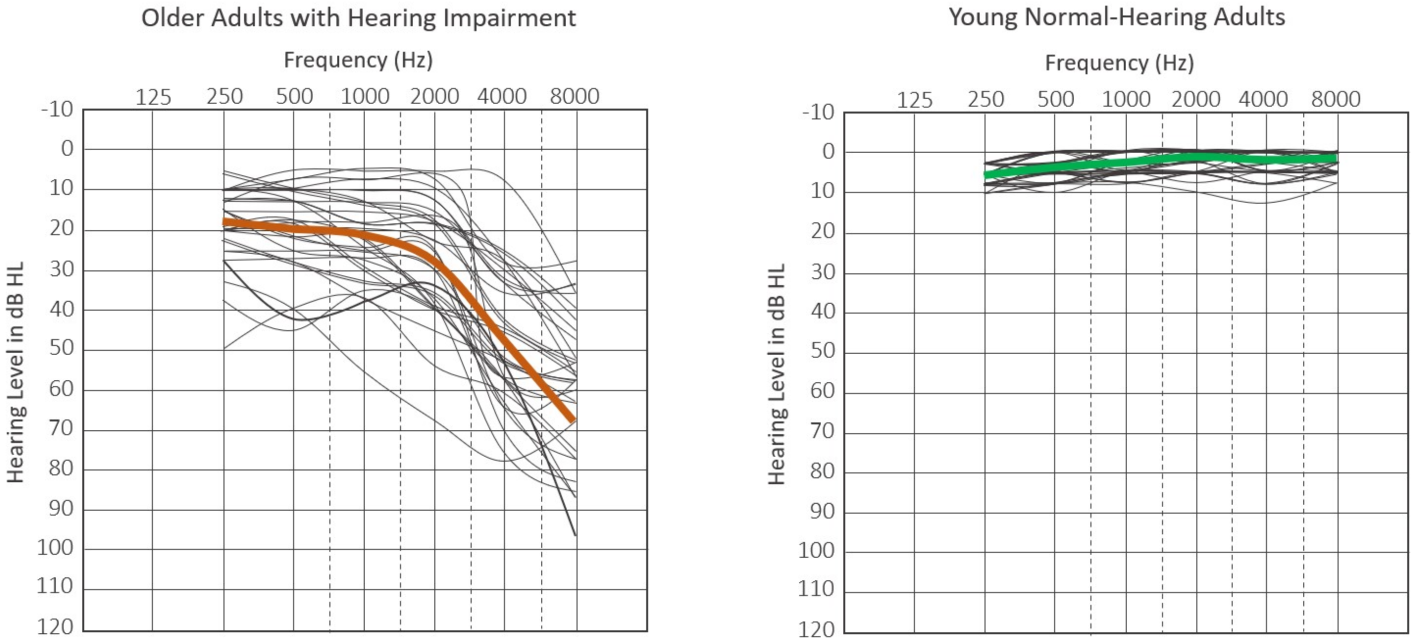

Figure 1. Audiograms showing hearing thresholds for older adults with hearing impairment (left) and young normal-hearing adults (right). Thin grey lines represent individual participants, and the thick colored lines (orange=older adults, green=younger adults) show group mean thresholds across frequencies (125–8000 Hz).

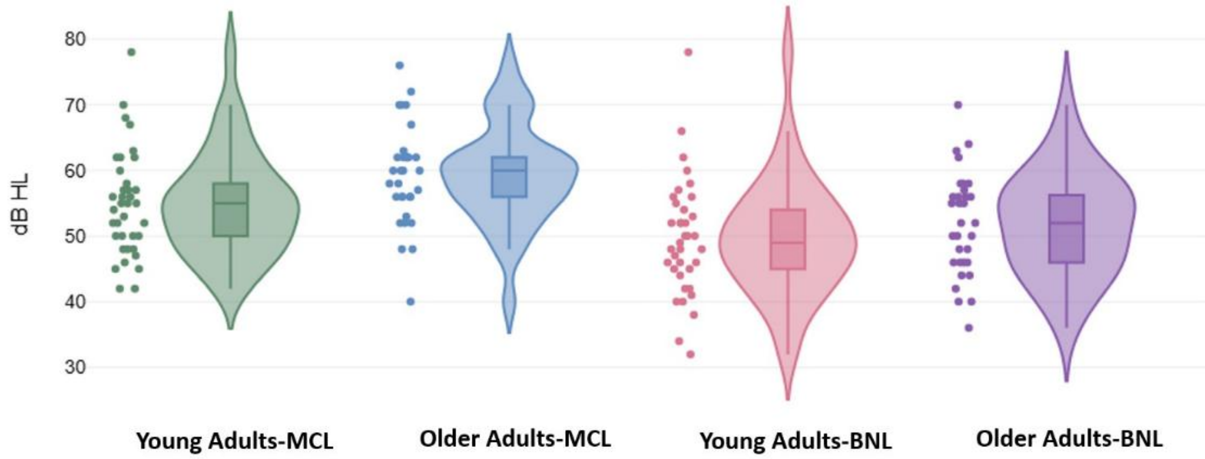

Figure 2. Violin plots showing the distributions of most comfortable level and background noise level for young normal-hearing adults and older adults with hearing impairment. The width of each violin represents the density of the data. The embedded box plots indicate the median (horizontal line), interquartile range (box), and minimum–maximum values (whiskers), and individual data points represent participant values. MCL; most comfortable level, BNL; background noise level

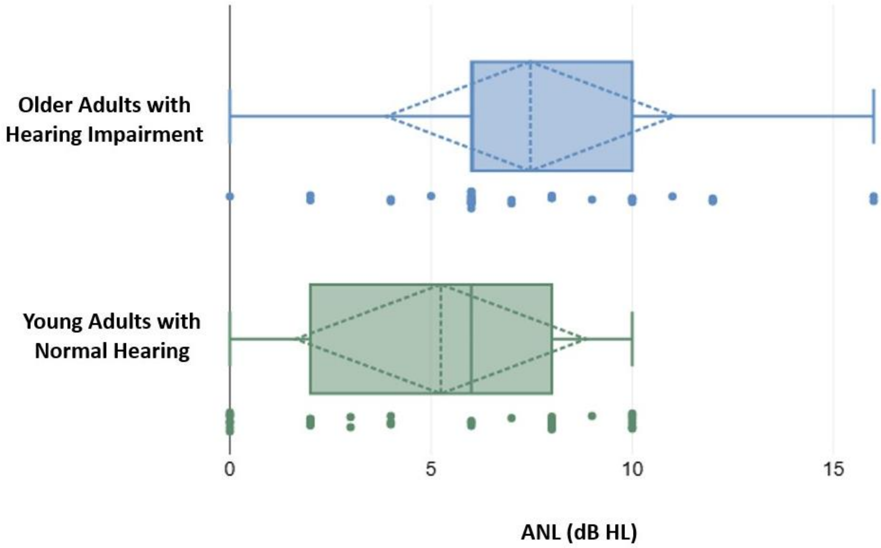

Figure 3. Box plot of acceptable noise level for older adults with hearing impairment and young normal-hearing adults. Boxes represent the interquartile range with the median shown as a vertical line; whiskers indicate minimum–maximum values, and individual data points represent participant values. ANL; acceptable noise level

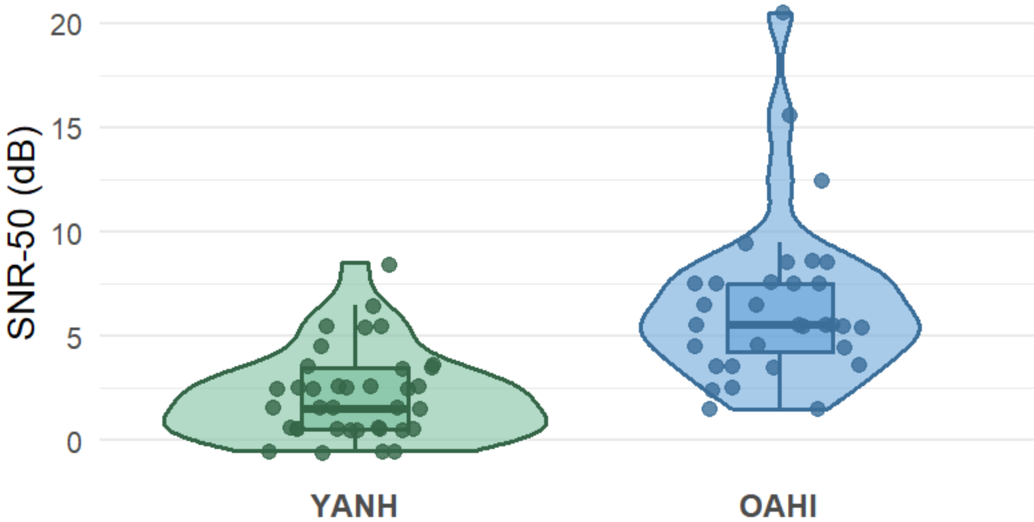

Figure 4. Distribution of SNR-50 values in young adults with normal hearing and older adults with hearing impairment (OAHI). Violin plots show the density of the data, with embedded boxplots indicating median and interquartile range. Individual data points are overlaid. SNR-50; signal-to-noise ratio required for 50% correct recognition, YANH; young adults with normal hearing, OAHI; older adults with hearing impairment