Auditory and Vestibular Research

Impact of High-Frequency Hearing Sensitivity on Speech Perception in Noise: Insights from the Perszian Quick Speech-in-Noise Test

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Highlights

High-frequency hearing loss (in 8000–12500 Hz) impairs speech perception in noise

High-frequency hearing thresholds and WRS predict speech-in-noise performance

Emphasizing high-frequency speech content improves hearing in noisy environments

Abstract

Background and Aim: Noise-induced hearing loss (NIHL) is a prevalent occupational concern, affecting high-frequency hearing sensitivity, which may impair speech perception in noisy environments. This study investigates the relationship between high-frequency hearing thresholds (4000–12500 Hz) and speech perception in noise, using the Persian Quick Speech-in-Noise (Quick SIN) test. The aim was to determine how these thresholds and speech perception in quiet correlate with and predict speech perception difficulties in noise.

Methods: A cross-sectional study was conducted on 288 participants aged 18–60 at the Center for Research on Occupational Diseases, Tehran University of Medical Sciences, from March to August 2024. Participants underwent audiometric testing for conventional (250–8000 Hz) and extended high-frequency (12500 Hz) thresholds, word recognition score (WRS), and the Persian Quick SIN test (basic and high-frequency lists). Pearson's and Spearman's correlations and multiple linear regression models evaluated relationships and predictive factors, with significance set at $p<0.05$.

Results: Strong positive correlations were observed between basic and high-frequency signal-to-noise ratio (SNR) loss and hearing thresholds at 4000–12500 Hz ($r/\rho=0.738$–0.84, $p<0.001$), with strong negative correlations with WRS ($\rho=-0.756$ to -0.785, $p<0.001$). Regression models identified 8000 and 12500 Hz thresholds, WRS, and education level as significant predictors of SNR loss ($R^2=0.764$–0.812). High-frequency list SNR loss was significantly lower than basic list SNR loss ($p<0.001$).

Conclusion: High-frequency hearing sensitivity, particularly at 8000 and 12500 Hz, significantly impacts speech perception in noise. Integrating high-frequency audiometry and speech-in-noise testing into occupational health assessments can improve early detection and management of NIHL.

Keywords: High-frequency hearing, extended high-frequency hearing, speech in noise, noise-induced hearing loss, quick speech-in-noise test

Introduction

Hearing loss is a major public health issue that significantly affects quality of life[1]. Among its causes, noise-induced hearing loss (NIHL) is a preventable disorder resulting from prolonged exposure to high-intensity sounds[2]. Its prevalence is increasing due to industrialization, urbanization, and recreational noise[1, 2]. The World Health Organization (WHO) reports that NIHL is the second leading cause of hearing impairment after presbycusis, accounting for about 16% of global hearing loss[3]. In Iran, roughly 34.69% of workers are affected by occupational NIHL[4]. Given its impact and preventability, effective strategies for early detection and management are crucial.

Conventional audiometric methods, such as pure-tone and speech audiometry, are widely used to diagnose NIHL[1, 4]. However, they are limited in detecting early-stage high-frequency hearing loss and in evaluating real-life listening, such as speech perception in noisy environments[5, 6]. These limitations highlight the need for more sensitive diagnostic tools. Speech perception in noise is a complex process requiring both auditory and cognitive skills, including filtering background noise and processing speech timing cues[7]. This ability is essential for effective communication[8]. Studies show that individuals with NIHL often struggle with speech perception in noise, even when audiometric thresholds appear normal[6, 9]. Thus, speech-in-noise testing may serve as a sensitive marker of early NIHL[10]. Several tests exist to evaluate speech perception in noise, including the Word in Noise (WIN), Bamford-Kowal-Bench Speech in Noise (BKB-SIN), Hearing in Noise Test (HINT), and Quick Speech in Noise (Quick SIN)[11]. The Quick Speech in Noise (Quick SIN) test is a well-established tool for assessing speech perception in noise[12]. The Quick SIN test is particularly valuable due to its sensitivity and ability to distinguish normal-hearing individuals from those with hearing loss[11-13]. These strengths make it a promising tool for early NIHL detection. High-frequency hearing sensitivity is another key indicator of NIHL[14]. The cochlea's basal region, responsible for high-frequency hearing, is highly vulnerable to noise damage[15]. Early NIHL often appears as hearing loss in extended high frequencies (above 8 kHz), even before lower-frequency thresholds decline[16, 17]. Thus, assessing high-frequency hearing can provide early diagnostic insights.

The relationship between high-frequency hearing and speech perception in noise has been a subject of ongoing research[5, 6, 18, 19]. Some findings suggest that reduced high-frequency sensitivity contributes to poorer speech-in-noise performance[5, 20]. For example, Motlagh Zadeh et al. reported that extended high-frequency loss reduced number recognition in noise, while amplification of high-frequency content improved thresholds[6]. However, results remain inconclusive, as some studies show inconsistent roles for extended high-frequency hearing in speech-in-noise perception[21]. Limitations of prior research include small sample sizes and a focus on normal-hearing participants, reducing applicability to noise-exposed populations with varying degrees of hearing loss.

Given that both extended high-frequency hearing and speech-in-noise perception are sensitive to occupational NIHL[14, 22], evaluating these measures in individuals referred to occupational health clinics may support their future use in early diagnosis. To date, no study has assessed the relationship between conventional and extended high-frequency hearing and speech-in-noise perception using the Persian Quick SIN test, despite the influence of linguistic differences on outcomes. The present study is novel in employing the Persian Quick SIN test to assess speech-in-noise perception in a large cohort with occupational noise exposure, focusing on both conventional (4000–8000 Hz) and extended high-frequency (12500 Hz) thresholds. It also investigates the predictive role of contextual factors, such as education, and compares basic versus high-frequency emphasized lists to assess the contribution of high-frequency speech content. These features enhance the clinical relevance of the findings for occupational health and the early management of NIHL.

This study aimed to explore the relationship between speech perception in noise, speech perception in quiet, and high-frequency thresholds in individuals referred to an occupational health clinic. By examining these variables, we sought to clarify factors contributing to hearing impairment in noise-exposed individuals. The results may have important implications for early detection, prevention, and management of NIHL in the workplace.

Methods

Participants

This cross-sectional, observational study was conducted on individuals aged 18 to 60 years attending the Center for Research on Occupational Diseases at Tehran University of Medical Sciences between March and August 2024. All participants worked in industrial and noisy environments with a documented history of occupational noise exposure. Inclusion criteria included: (1) age range between 18 and 60 years; (2) no history of ear, nose, and throat diseases (e.g., Meniere's disease, otosclerosis); (3) absence of significant cognitive disorders or intellectual disability, confirmed by a minimum score of 24 on the Mini-Mental State Examination (MMSE); (4) no history of chronic neurological disorders; (5) no history of chronic psychiatric disorders; (6) no history of severe head or neck trauma; and (7) no history of using ototoxic drugs (e.g., aminoglycosides). Participants were excluded if they exhibited a Pure Tone Average (PTA) greater than 25 dB HL (at frequencies of 500, 1000, and 2000 Hz), or had asymmetrical hearing thresholds between ears (difference exceeding 10 dB at any tested frequency).

Participants were recruited through convenience sampling. The required sample size was calculated using G*Power version 3.1.9.7, considering a type I error (α) of 0.05, a power (1-β) of 90%, and an effect size of $\omega^2 = 0.03$. This calculation yielded a sample size of 288 participants. The study adhered to the ethical principles outlined in the Declaration of Helsinki, and all participants provided written informed consent. The Ethics Committee of Tehran University of Medical Sciences approved the study protocol (Approval ID: IR.TUMS.FNM.REC.1402.246).

Study procedure

Eligible participants were informed about the study and gave written consent. They then underwent audiometric evaluations assessing hearing thresholds and speech perception in quiet and noise, conducted in a soundproof room using the Madsen Itera II audiometer (GN Otometrics, Taastrup, Denmark). Thresholds were measured at 250–8000 Hz, 6000 Hz, and 12500 Hz. Participants with PTA >25 dB HL or asymmetrical thresholds were excluded. Speech perception in quiet was assessed using the word recognition score (WRS). Monosyllabic words were presented binaurally at the Most Comfortable Level (MCL). Participants repeated each word, and WRS was calculated as the percentage of correct responses. Because hearing thresholds were symmetric (≤10 dB difference at tested frequencies) and to replicate real-world listening conditions, pure-tone and speech audiometry were conducted binaurally, with stimuli presented simultaneously and equally to both ears.

Speech-in-noise perception was evaluated using the Persian version of the Quick Speech-in-Noise (Quick SIN) test, developed by Fatahi et al.[23]. This test measures the signal-to-noise ratio (SNR) loss, an index reflecting difficulty in understanding speech in noisy environments. Similar to the original English version, this version consists of 18 lists. The first six lists are the basic lists. lists seven to twelve are composed of frequently used and familiar words in Persian, and lists thirteen to eighteen are the same six basic lists with high-frequency speech content emphasized by 30 dB. Each list comprises six sentences spoken by a female voice, accompanied by four-talker babble noise. Test sentences were presented at fixed SNRs ranging from 25 to 0 dB in 5 dB decrements. During the test, speech intensity remained constant (presented at 70 dB) while noise intensity increased. Speech and noise stimuli were presented binaurally and diotically. Participants were instructed to imagine being in a social gathering and focus on the main speaker's sentences despite increasing background noise. They were required to repeat each sentence immediately after hearing it. The number of correctly repeated keywords (up to five per sentence) was recorded, and the total score for each list was calculated. The SNR loss was calculated using the following formula:

SNR loss = 27/5 - (total number of correct words in each list) - SNR 50

The SNR 50 value (the signal-to-noise ratio at which a normal-hearing individual can correctly understand and repeat 50% of the presented words) varies in each language depending on its characteristics, especially its overall redundancy. Previous studies on the Persian Quick SIN test have reported SNR 50 values ranging from -0.25 dB to -4 dB[23, 24]. To account for this variability and enhance the accuracy of our analysis, we adopted an approximate average SNR 50 value of -2 dB for the Persian language in this study.

Considering high-frequency contributions to speech perception, both the basic lists and the high-frequency emphasized lists were utilized. Specifically, baseline lists 1 and 3 were used to calculate the average baseline SNR loss, and high-frequency lists 16 and 18, which are the high-frequency emphasized versions of baseline lists 4 and 6, were used to calculate the average high-frequency SNR loss for each participant. The SNR loss for each list was calculated and recorded separately. For each type of list, the average SNR loss from the two reliable and comparable lists was taken as the final index for that condition.

Statistical analysis

Data were analyzed using SPSS version 17. The Shapiro-Wilk test was employed to assess the normality of data distribution. Pearson's correlation coefficient was used to examine relationships between variables for normally distributed data, while Spearman's correlation coefficient was applied for non-normally distributed data. Paired t-tests compared SNR loss between basic and high-frequency lists. Multiple linear regression analysis explored the predictive role of WRS and high-frequency hearing thresholds (4000 Hz to 12500 Hz) in determining basic and high-frequency SNR loss indices. For each of these indices, before fitting the main regression model, a preliminary linear regression analysis was used to determine the potential effects of each independent and contextual variable on speech perception in noise (SNR loss). Contextual variables included age, gender, education level, work experience, and marital status. Independent and contextual variables that had a significant effect on predicting SNR loss in the preliminary regression model were used in the final (main) regression model to obtain the regression equation. Statistical significance was set at $\alpha = 0.05$.

Results

This study investigated the relationships between speech perception in noise (basic SNR loss and high-frequency SNR loss), speech perception in quiet (WRS), and high-frequency pure tone thresholds in 288 participants. The participants were all recruited from the Center for

Research on Occupational Diseases at Tehran University of Medical Sciences. **Table 1.** demonstrates the demographic data and basic evaluation results of the participants**.**

Normality test

The Shapiro-Wilk test was employed to assess the normality of variables. The results revealed that variables, including 6000 Hz threshold ($p = 0.111$), 8000 Hz threshold ($p = 0.057$), basic SNR loss ($p = 0.241$), and high-frequency SNR loss ($p = 0.177$), followed a normal distribution. Conversely, other variables, including 4000 Hz threshold ($p = 0.021$), 12500 Hz threshold ($p < 0.001$), and WRS ($p < 0.001$) did not conform to a normal distribution.

Correlation between basic signal-to-noise ratio loss and target variables

Pearson's and Spearman's correlation analyses were performed to explore the relationships between basic SNR loss and the variables in question. For normally distributed variables, a strong positive correlation was observed between basic SNR loss and 6000 Hz threshold ($r = 0.758$, $p < 0.001$) and 8000 Hz threshold ($r = 0.801$, $p < 0.001$). For non-normally distributed variables, strong positive correlations were found between basic SNR loss and 4000 Hz threshold ($\rho = 0.795$, $p < 0.001$). In addition, a very strong positive correlation was observed between basic SNR loss and the 12500 Hz threshold ($\rho = 0.84$, $p < 0.001$). In contrast, the WRS exhibited a strong negative correlation with basic SNR loss ($\rho = -0.785$, $p < 0.001$). **Figure 1.** shows the relationship between basic SNR loss and target variables.

Correlation between high-frequency signal-to-noise ratio loss and target variables

Analyzing the relationship between high-frequency SNR loss and the variables of interest yielded similar findings. Pearson's correlation analysis showed strong positive correlations between high-frequency SNR loss and 6000 Hz threshold ($r = 0.738$, $p < 0.001$) and 8000 Hz threshold ($r = 0.785$, $p < 0.001$). In addition, Spearman's correlation analysis revealed a strong positive relationship between high-frequency SNR loss and 4000 Hz threshold ($\rho = 0.779$, $p < 0.001$) and 12500 Hz threshold ($\rho = 0.809$, $p < 0.001$). A strong negative correlation between high-frequency SNR loss and WRS was also observed ($\rho = -0.756$, $p < 0.001$). **Figure 2.** demonstrates the correlation between high-frequency SNR loss and target variables.

Correlation between word recognition score and hearing thresholds at 4000-12500 Hz

Spearman's correlation analysis examined the relationship between WRS and hearing thresholds at 4000-12500 Hz. Strong negative correlations were found between WRS and 4000 Hz threshold ($\rho = -0.709$, $p < 0.001$), 6000 Hz threshold ($\rho = -0.679$, $p < 0.001$), 8000 Hz threshold ($\rho = -0.692$, $p < 0.001$), and 12500 Hz threshold ($\rho = -0.656$, $p < 0.001$). **Figure 3.** shows the correlation between WRS and high-frequency hearing thresholds (4000 to 12500 Hz).

Predicting basic signal-to-noise ratio loss using the selected variables

We conducted two multiple linear regressions (Preliminary and final) to predict basic SNR loss based on contextual variables, WRS and hearing thresholds at 4000-12500 Hz.

The preliminary regression model was significant ($F_{(10.266)}$=114.688, p<0.001, R^2=0.81) and accounted for 81% of the variation in basic SNR loss. In addition, the results indicated that among the selected variables, 8000 Hz threshold (t=3.918, p<0.001, β=0.307), 12500 Hz threshold (t=8.002, p<0.001, β=0.393), WRS (t=-8.390, p<0.001, β=-0.320), and education level (t=-2.057, p=0.041, β=-0.065) were significant in the regression model and contributed to predicting SNR loss. These variables were then used to fit the main regression model. Other variables did not have a significant effect on predicting basic SNR loss (p>0.05). The results of the preliminary regression model are shown in **Table 2.**

Another regression model (final model) was used to determine the relative contribution of each variable in predicting SNR loss and to obtain the regression equation. The final regression model was significant ($F_{(4.266)}$=288.146, p<0.001, R^2=0.812) and accounted for 81.2% of the variation in basic SNR loss. Additionally, the results showed that the variables 12500 Hz threshold (t=8.211, p>0.001, β=0.360), 8000 Hz threshold (t=7.308, p>0.001, β=0.327), WRS (t=-8.725, p>0.001, β=-0.317), and education level (t=-2.109, p=0.036, β=-0.056) had the greatest impact on basic SNR loss, respectively. Based on the results, the regression equation is as follows:

Y = 10.518 - 0.123X1 + 0.055X2 + 0.058X3 - 0.093X4

Where; Y: Basic SNR loss, X1: Education level, X2: 8000 Hz threshold, X3: 12500 Hz threshold, and X4: WRS

The equation shows that, assuming hearing thresholds at 8000 and 12500 Hz remain constant, increasing education level or WRS decreases SNR loss and improves speech perception in noise. Conversely, assuming education level and WRS remain constant, increasing either 8000 or 12500 Hz threshold increases SNR loss and deteriorates speech perception in noise.

Predicting high-frequency signal-to-noise ratio loss using the selected variables

To predict high-frequency SNR loss based on contextual variables, WRS, and hearing thresholds at 4000-12500 Hz, we used two multiple linear regression analyses (preliminary and final) similar to the previous section.

The preliminary regression model was significant ($F_{(10.266)}$=87.029, p<0.001, R^2=0.764), accounting for 76.4% of the variation in high-frequency SNR loss. Additionally, the results demonstrated that among the selected variables, 8000 Hz threshold (t=4.524, p<0.001, β=0.395), 12500 Hz threshold (t=5.823, p<0.001, β=0.319), and WRS (t=-6.652, p<0.001, β=-0.283) were significant in the regression model and contributed to predicting SNR loss. These variables were used to fit the main regression model. Other independent and contextual variables did not have a significant effect on predicting high-frequency SNR loss (p>0.05). The results of the preliminary regression model are shown in **Table 2.**

The final regression model was used to determine the relative contribution of each variable in predicting SNR loss and to obtain the regression equation. The final regression model was significant ($F_{(3.266)}$=287.734, p<0.001, R^2=0.764), accounting for 76.4% of the variation in high-frequency SNR loss. Further, the results showed that the variables 8000 Hz threshold (t=7.632, p<0.001, β=0.382), 12500 Hz threshold (t=6.455, p<0.001, β=0.317), and WRS (t=-8.946, p<0.001, β=-0.281) had the greatest contribution in predicting high-frequency SNR loss, respectively. The regression equation for predicting high-frequency SNR loss is as follows:

Y = 8.027 + 0.057X1 + 0.045X2 - 0.073X3

Where; Y: High-frequency SNR loss, X1: 8000 Hz threshold, X2: 12500 Hz threshold, and X3: WRS

The equation reveals that assuming hearing thresholds at 8000 and 12500 Hz remain constant, increasing WRS decreases SNR loss and improves speech perception in noise. Conversely, assuming the WRS remains constant, increasing either the 8000 or 12500 Hz threshold increases SNR loss and deteriorates speech perception in noise.

Comparison of mean signal-to-noise ratio loss for basic and high-frequency lists

A paired sample t-test revealed a significant difference in mean SNR loss between basic and high-frequency lists (t_{287}=15.88, p<0.001). The result indicates that enhancing the high-frequency content of speech significantly reduces mean SNR loss and improves speech perception in noise. **Figure 4.** shows the mean SNR loss for basic and high-frequency lists.

Discussion

This study investigated the relationship between speech perception in noise, speech perception in quiet, and high-frequency pure-tone thresholds in individuals referred to the Center for Research on Occupational Diseases at Tehran University of Medical Sciences. The findings demonstrated a strong correlation between high-frequency hearing thresholds and speech perception performance in quiet and noisy environments, highlighting the importance of high-frequency sensitivity in speech processing, particularly in challenging conditions.

The correlation analysis revealed a strong negative association between monosyllabic word recognition scores (WRS) and hearing thresholds at frequencies ranging from 4000 to 12500 Hz. As hearing thresholds increased at these frequencies, WRS significantly decreased, indicating that high-frequency hearing plays a crucial role in speech perception. These results are consistent with the findings of previous studies conducted by Li et al. and Patro et al., which highlighted the detrimental effects of high-frequency hearing loss on speech perception[25, 26]. Historically, it was believed that frequencies below 4 kHz were primarily responsible for speech perception, with limited contributions from higher frequencies[27]. However, these results align with previous research and demonstrate the crucial role of frequencies above 7 kHz in speech perception, particularly in noisy environments where distinguishing speech from background noise is essential[27, 28]. Studies have shown that high-frequency acoustic information contributes to the recognition of consonants and vowels, speech localization, and speech-in-noise performance[29-31]. This underscores the need for evaluating high-frequency and extended high-frequency hearing in clinical assessments, especially in populations exposed to occupational noise.

A remarkable finding of this study is the strong correlation of high-frequency thresholds, particularly at 12500 Hz, with SNR loss in both baseline and high-frequency lists. These findings align with previous research emphasizing the critical role of extended high-frequency hearing sensitivity in speech perception[6, 18, 30]. Studies by Badri et al. and Motlagh Zadeh et al. corroborate the results of present study, demonstrating that individuals with impaired extended high-frequency hearing experience significant challenges in understanding speech in noise, despite having normal hearing at lower frequencies[6, 18]. This suggests extended high-frequency hearing is vital for effective speech perception in noisy environments. The propagation characteristics of high-frequency sounds, which are less susceptible to environmental reflections and more directly transmitted to the listener, contribute to their critical role in distinguishing speech signals in complex auditory environments[30, 32, 33]. However, the findings of the present study show some discrepancies with studies such as Koerner and Gallun, which found no significant differences in extended high-frequency hearing sensitivity between groups with and without speech perception difficulties in noise[21]. These discrepancies could be attributed to differences in study methodologies, participant characteristics, and the calibration of audiometric equipment, emphasizing the need for standardized testing approaches in future research.

The regression models developed in this study showed that hearing thresholds at 8000 and 12500 Hz, along with WRS, were the most significant predictors of speech perception performance in noise, as measured by SNR loss indices in the Quick SIN test. Further, the findings suggest that education level also plays a role in predicting speech perception in noise, highlighting the influence of cognitive and linguistic factors in speech processing abilities. These findings, consistent with studies by Yeend et al. [19] and Yeend et al. [34], indicate that speech perception in noise is a complex and multifaceted process that is influenced by auditory and cognitive factors [19, 34]. It is suggested that the assessment of these factors can be considered during clinical examinations of individuals with normal hearing who have difficulty perceiving speech in noise.

A comparison of the mean SNR loss indices between the baseline and high-frequency lists revealed a significant reduction in SNR loss with the high-frequency lists. This suggests that emphasizing high-frequency components of speech can enhance speech perception performance in noise. This finding is consistent with a study by Motlagh Zadeh et al., which demonstrated that amplification of high-frequency spectral components improves speech recognition in noise[6].

Given the high prevalence of noise-induced hearing loss (NIHL) among occupational populations, the findings of this study underscore the importance of integrating high-frequency audiometry and speech-in-noise tests into routine hearing assessments. Early detection of high-frequency hearing loss allows for timely interventions, which can help prevent the progression of hearing impairments and enhance individuals' communication abilities in noisy environments. Furthermore, workplace health programs should include periodic monitoring of high-frequency hearing sensitivity to proactively address occupational hearing risks and implement protective strategies, such as noise exposure controls and the use of appropriate hearing protection devices.

Despite valuable insights, several limitations must be noted. The cross-sectional design prevents establishing causality between high-frequency hearing loss and speech perception deficits. Hearing thresholds were measured only up to 12.5 kHz due to audiometer limitations, excluding higher frequencies (14–16 kHz) typically assessed in extended high-frequency audiometry. This may restrict the generalizability of our findings on the role of extended high-frequency hearing in speech perception. Longitudinal studies with larger, more diverse populations and equipment capable of testing higher frequencies are needed to validate these results and examine long-term effects. Although binaural assessments were used to reflect real-world listening, future work should also employ monaural assessments, as these are standard in clinical practice and may reveal ear-specific effects. Additionally, while our models explained substantial variance in SNR loss, factors such as central auditory processing and cognitive load were not addressed and should be examined. The study also did not address the duration or specific cause of high-frequency hearing loss. Participants' work experience may reflect duration of noise exposure, but this was not directly analyzed, and other etiologies may have contributed. Future research should examine how duration and etiology influence speech-in-noise performance, incorporating detailed assessments to isolate specific causes of high-frequency hearing loss. Furthermore, it is recommended that future research expand beyond individuals with high-frequency impairments to include other types and degree of hearing loss. Comparative evaluations should be conducted to assess the impact of hearing loss across different frequency spectra on speech-in-noise comprehension.

Conclusion

The results of this study provide strong evidence supporting the role of high-frequency hearing sensitivity, particularly at 8000 and 12500 Hz, in speech perception in noise. The findings emphasize the importance of incorporating high-frequency audiometry and speech-in-noise testing in clinical assessments for early detection of noise-induced hearing loss. Furthermore, the study highlights the contribution of cognitive and linguistic factors, such as education level, to speech perception abilities, suggesting that comprehensive speech-in-noise assessments should include both auditory and cognitive measures. Future research should explore longitudinal studies to assess the progression of high-frequency hearing loss and its impact on speech perception over time. Overall, these findings contribute to a better understanding of the factors influencing speech perception in noise and provide valuable insights for occupational health interventions aimed at mitigating the effects of noise exposure.

Declarations

Conflict of interest statement

The authors have no conflict of interest to declare.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Tehran University of Medical Sciences (Date: 2024-03-16/No. IR.TUMS.FNM.REC.1402.246).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Data availability statement

Data will be made available on request.

Author's contribution

SN: Study design, acquisition of data, statistical analysis, interpretation of results, drafting the manuscript, and critical revision of the manuscript; GP: Study design, project supervision, interpretation of results, and critical revision of the manuscript, RM: Study design, statistical analysis, and critical revision of the manuscript; FF: Study design, technical and material support, and critical revision of the manuscript; TV: technical and material support.

All authors reviewed and approved the final version of the manuscript.

Acknowledgments

This study was partially supported by Tehran University of Medical Sciences (grant number 1402-4-169-68269). The funding source had no role in the design, data collection, analysis, interpretation, or publication of the research. The authors gratefully acknowledge all participants for their valuable time and contributions, which were essential to the success of this study.

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Table 1. Demographic data and evaluation results of the participants.

Variable	**Value**
Age (Year) (Mean±SD)	37.09±8.416
Gender	
Male (n)	208
Female (n)	80
Education Level	
Middle school (n)	15
Diploma (n)	83
Associate (n)	27
Bachelor (n)	111
Master (n)	46
Doctorate (n)	6
Work experience (Year) (Mean±SD)	10.63±8.618
Marital status	
Single (n)	147
Married (n)	141
PTA (dB HL) (Mean±SD)[a]	8.3±7.586
4000 Hz threshold (dB HL) (Mean±SD)[a]	30.97±17.212
6000 Hz threshold (dB HL) (Mean±SD)[a]	33.92±16.915
8000 Hz threshold (dB HL) (Mean±SD)[a]	30.66±16.286
12500 Hz threshold (dB HL) (Mean±SD)[a]	43.6±16.763
WRS (%) (Mean±SD)[a]	84.6±9.246
Basic SNR loss (dB) (Mean±SD)[a]	6.35±2.835
High-Frequency SNR loss (dB) (Mean±SD)[a]	5.44±2.472

[a] Binaurally evaluated

Table 2. Preliminary regression models result for both basic and high-frequency signal-to-noise ratio loss variables.

	Basic SNR loss				**High-frequency SNR loss**			
	b	**β**	**t**	**p-value**	**b**	**β**	**t**	**p-value**
(Constant)	10.566	-	8.135	**<0.001***	8.411	-	6.612	**<0.001***
Age	0.011	0.035	0.512	0.609	-0.017	-0.058	-0.765	0.445
Gender	-0.189	-0.032	-1.14	0.255	0.239	0.045	1.46	0.146
Education level	-0.142	-0.065	-2.057	**0.041***	-0.071	-0.037	-1.043	0.298
Work experience	-0.007	-0.022	-0.358	0.720	0.024	0.083	1.219	0.224
Marital status	0.089	0.017	0.529	0.598	0.034	0.007	0.2	0.841
4000 Hz Threshold	-0.014	-0.089	-1.395	0.164	-0.003	-0.019	-0.269	0.788
6000 Hz Threshold	0.008	0.047	0.628	0.530	-0.002	-0.015	-0.177	0.86
8000 Hz Threshold	0.051	0.307	3.918	**<0.001***	0.058	0.395	4.524	**<0.001***
12500 Hz Threshold	0.063	0.393	8.002	**<0.001***	0.045	0.319	5.823	**<0.001***
WRS	-0.094	-0.32	-8.39	**<0.001***	-0.074	-0.283	-6.652	**<0.001***

*Statistically significant ($p<0.05$)

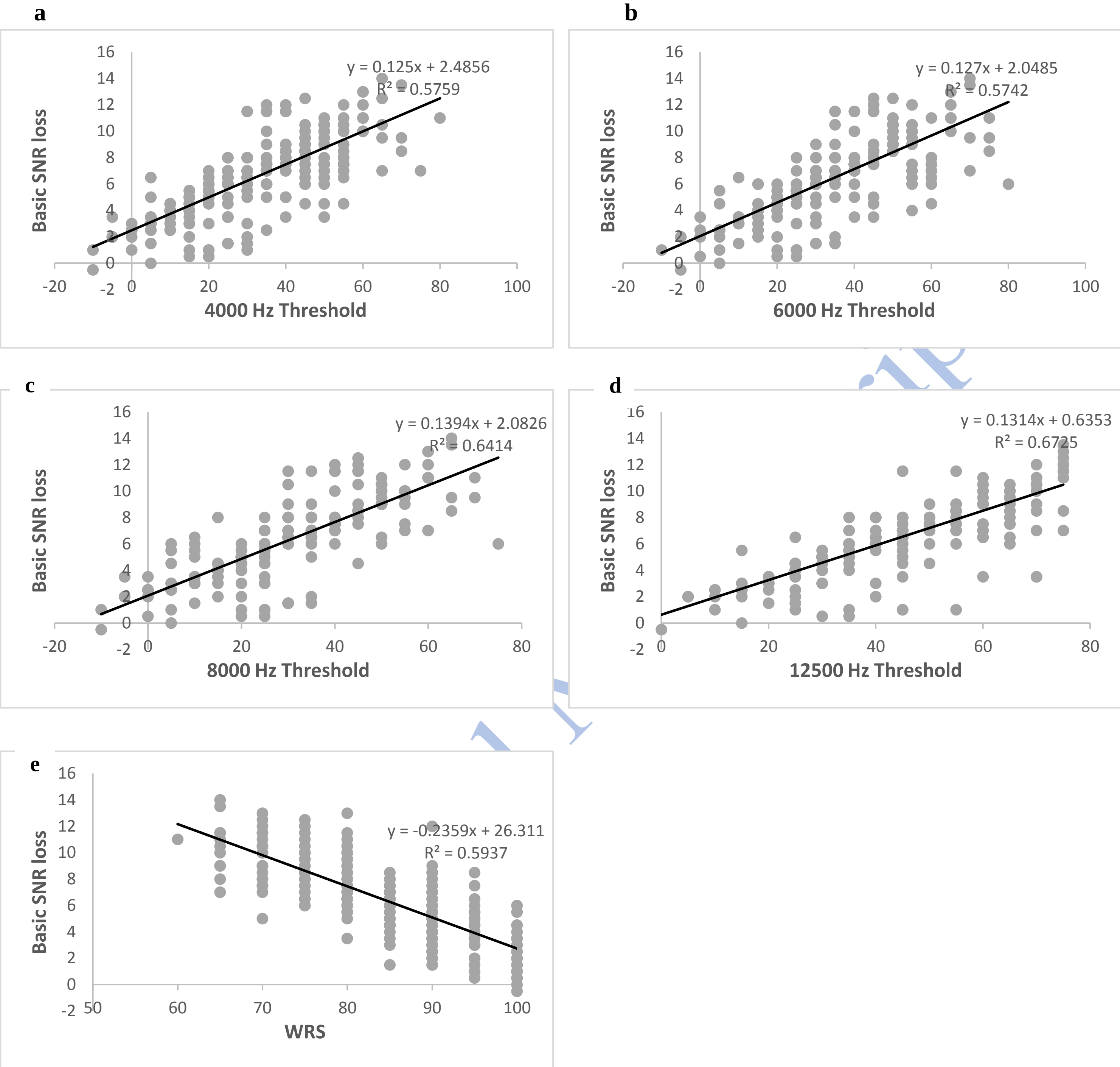


Figure 1. Relationship between basic SNR loss and target variables. Scatterplots demonstrate basic SNR loss as a function of **a)** 4000 Hz threshold, **b)** 6000 Hz threshold, **c)** 8000 Hz threshold, **d)** 12500 Hz threshold, and **e)** WRS.

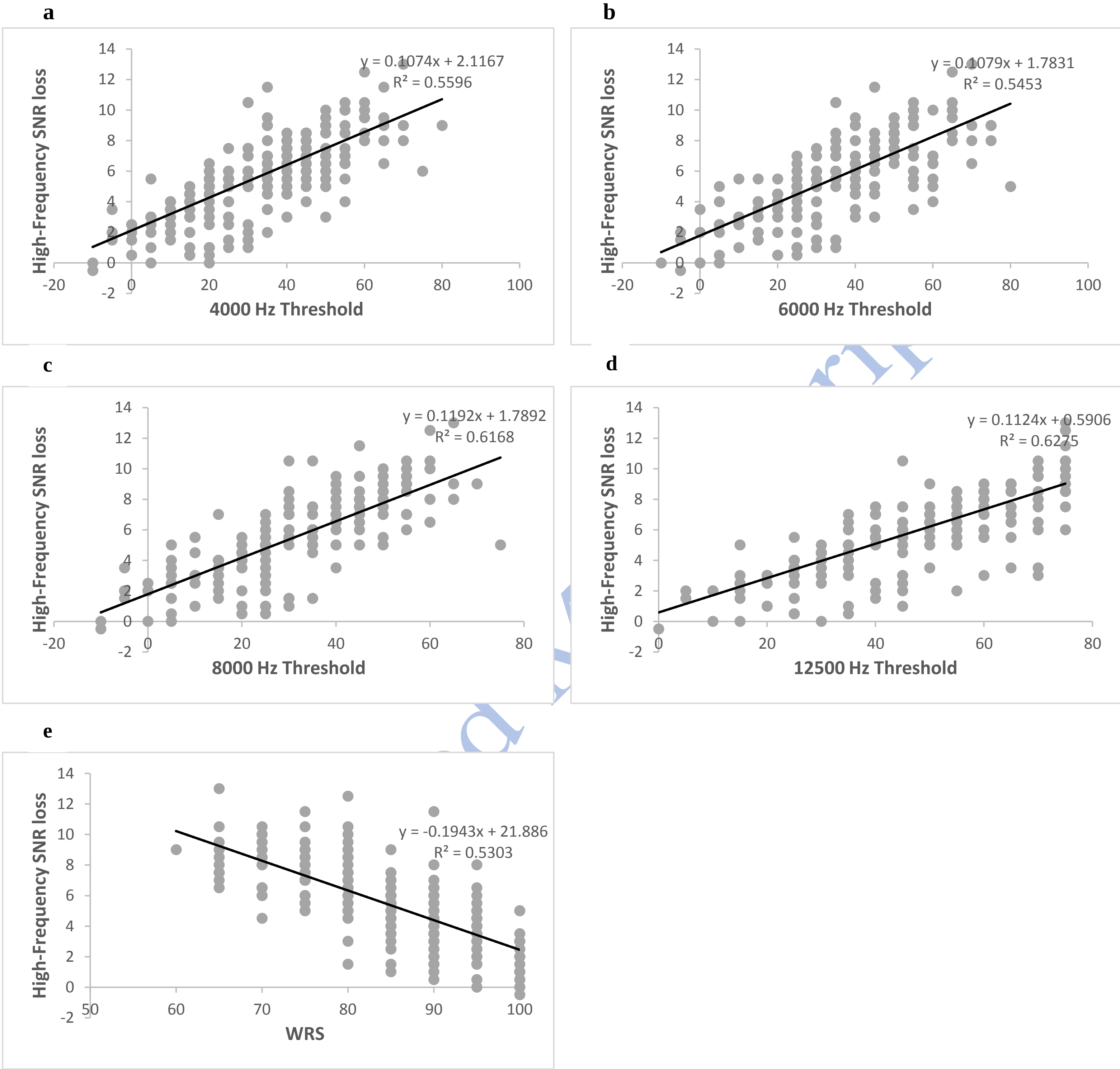
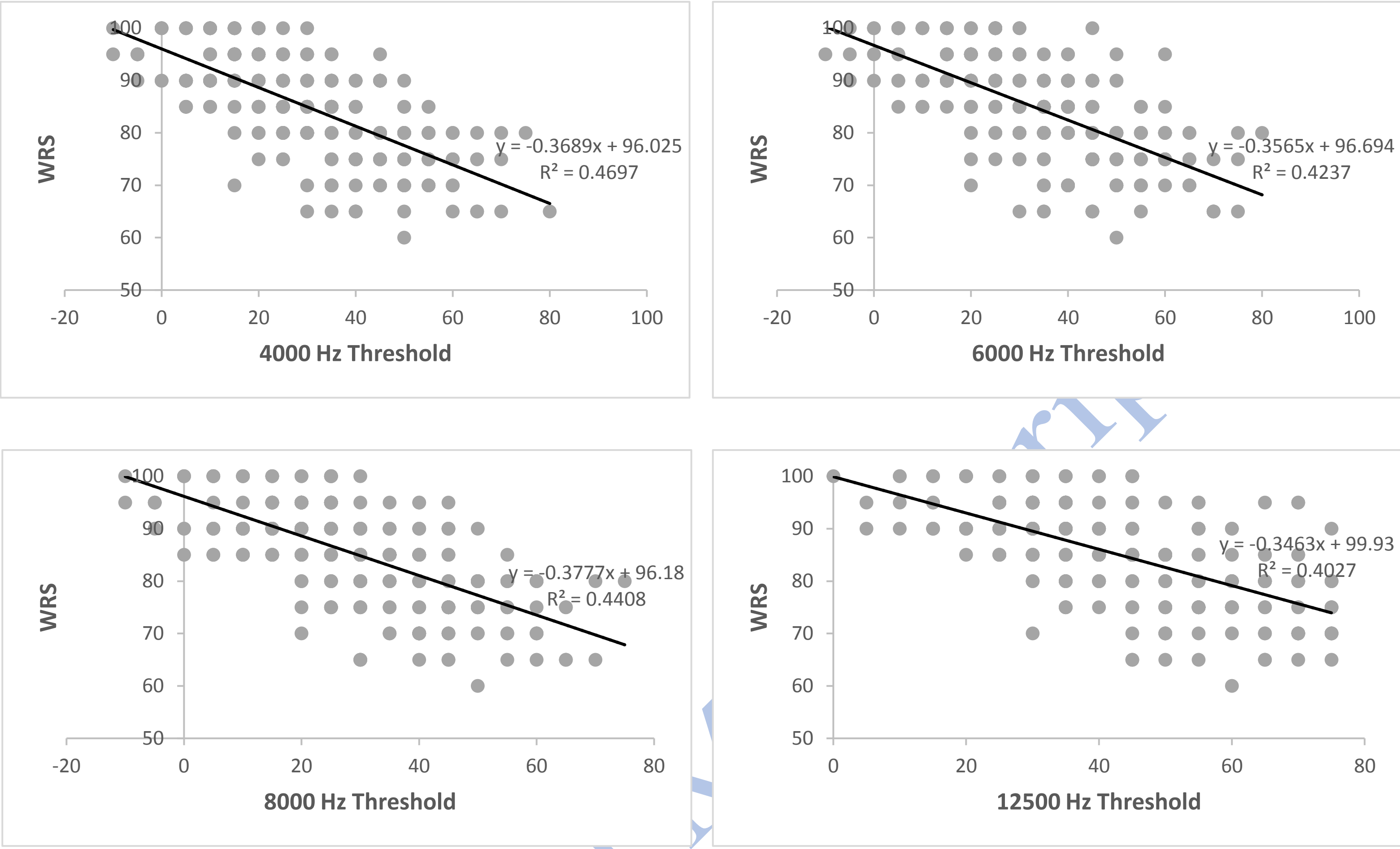


Figure 2. Relationship between high-frequency SNR loss and target variables. Scatterplots demonstrate high-frequency SNR loss as a function of **a)** 4000 Hz threshold, **b)** 6000 Hz threshold, **c)** 8000 Hz threshold, **d)** 12500 Hz threshold, and **e)** WRS.

a b



c d

Figure 3. Relationship between WRS and high-frequency hearing thresholds (4000 to 12500 Hz). Scatterplots demonstrate WRS as a function of **a)** 4000 Hz threshold, **b)** 6000 Hz threshold, **c)** 8000 Hz threshold, and **d)** 12500 Hz threshold.

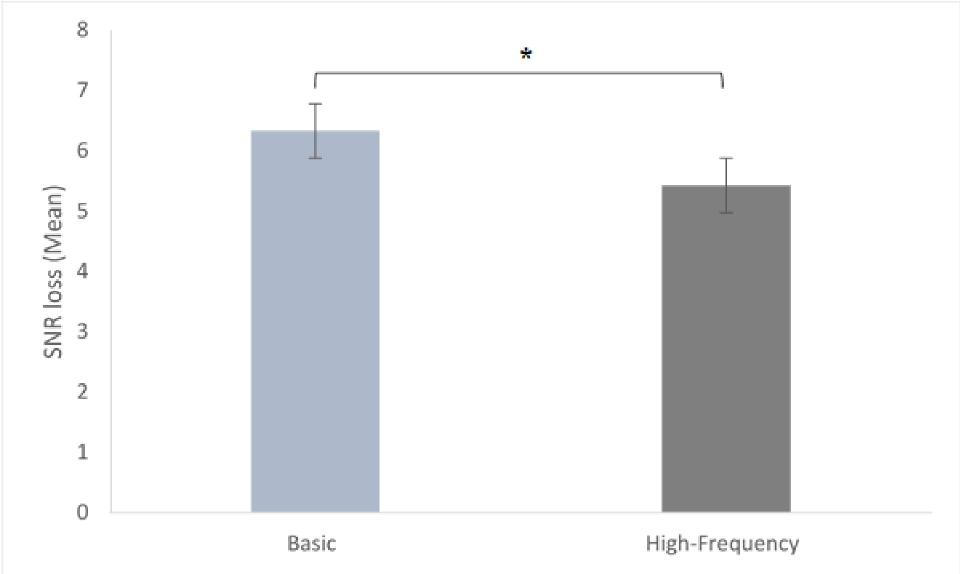


Figure 4. The mean SNR loss for basic and high-frequency lists (* p<0.001).