Research Article

Auditory Recognition of Words-in-Noise in Normal Hearing and Mild-to-Severe Sensorineural Hearing Loss with Different Configurations

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Citation: Nasiri E, Jalilvand H, Mahdavi ME, Koravand A. Auditory Recognition of Words-in-Noise in Normal Hearing and Mild-to-Severe Sensorineural Hearing Loss with Different Configurations. Aud Vestib Res. 2024;33(2): 110-7.

https://doi.org/10.18502/avr.v33i2.14813

Highlights

- The signal-to-noise ratio (SNR) slope varies for various hearing levels
- Adults with SNHL require more 7–14 dB SNR than normal-hearing people for ARWIN
- With the increase of hearing loss, the required SNR for ARWIN increases

Article info:
Received: 06 Jun 2023
Revised: 07 Aug 2023
Accepted: 12 Sep 2023

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ABSTRACT

Background and Aim: Sensorineural Hearing Loss (SNHL) reduces audibility and causes distortion, which result in difficulty with speech processing, especially in noisy environments. One of the new speech-in-noise tests is the Words-in-Noise (WIN) test. This study aimed to further investigate the Signal-to-Noise Ratio 50% (SNR-50) in subjects with mild to severe SNHL and different configurations using the Persian version of the WIN test compared to normal-hearing people.

Methods: This cross-sectional study was conducted on 54 patients with SNHL aged 17–75 years and 49 normal-hearing people aged 20–48 years. The auditory recognition in the presence of multi-talker babble noise was evaluated by the Persian version of the WIN test (named ARWIN).

Results: The mean SNR-50 in the normal-hearing group was 2.56±1.2 dB, which increased significantly in subgroups with mild (10.13±4.8 dB), moderate (14.51±4.7 dB) and moderate-to-severe (16.61±4.3 dB) SNHL ($p<0.001$).

Conclusion: People with SNHL need more SNR by nearly 4–6 times than the normal-hearing group for recognition of monosyllabic Persian words in the presence of multi-talker babble noise.

Keywords: Sensorineural hearing loss; words-in-noise; auditory recognition; speech perception

Introduction

One of the main complaints of people with Sensorineural Hearing Loss (SNHL) is speech perception in noise. Most of these people state that they hear speech in noisy environments but do not understand it [1]. Many studies have recommended to measure the performance of speech perception in the presence of background noise and have emphasized that the speech perception in noise test should be included in the basic audiological test battery because traditional hearing tests such as pure tone audiometry, Speech Reception Threshold (SRT), and Word Recognition Score (WRS) cannot measure the performance in the presence of noise [2-4]. A low-level noise that is slightly disruptive for a listener with normal hearing may be a serious interference for a listener with SNHL [5]. Two hearing-impaired subjects with nearly the same Pure Tone Average (PTA) may show 15–20 dB differences in Signal-to-Noise Ratio (SNR) loss [6]. Due to the importance of evaluating speech perception in noise, various tests that use sentence materials such as the connected speech test [7], hearing in noise test [8], and the quick speech-in-noise test [9] have been developed. In daily life, we communicate with others by employing sentences; this is the rationale for using sentences to construct these tests. Although sentences have higher face validity compared to monosyllabic digits and words, sentence recognition requires understanding the whole sentence and sufficient brain processing speed, cognitive skills, and working memory capacity, which may be weak in an older adult. On the other hand, the syntactic, semantic, and contextual cues may help the listener to repeat a sentence correctly without recognizing its keywords [10, 11]. Although the use of digits and words as speech materials has also been criticized from some aspects, they are used as popular materials by audiologists due to minimizing the effect of working memory and linguistic context [12]. Compared to the tests in which the sentences in noise are used, the main advantages of the Words-in-Noise (WIN) test is applying same materials as monosyllabic words in quiet that are used in the basic speech audiometry tests in clinical practice. Furthermore, the WIN test assesses auditory factors more effectively than the sentence-in-noise test. The recognition of sentences in noise involves more top-down processing than the recognition of words in noise, which mainly depends on encoding perceptual information [11].

Currently, audiologists usually use less Speech-in-Noise (SIN) tests for various reasons, such as unfamiliarity with the tests and their interpretations [13], while the results of SIN tests can be useful in choosing amplification strategies and SNR enhancement methods (frequency modulation and directional microphones), informing patients about the advantages or limitations of their hearing aids and having realistic expectations when using hearing aids in noisy environments [10, 14]. After extensive studies on the words used in the Northwestern University Auditory Test Number Six test in quiet and noise, the WIN test was developed by Wilson in 2003 [5]. This test included 70 monosyllabic words, divided into two 35-word lists to make clinical use easier [15]. The background noise in the WIN test is a six-talker babble, which remains constant during the test. The level of the target words decreases in 4 dB steps. Therefore, there are 7 SNRs from +24 to 0 dB, and 5 words are presented in each SNR. In this test, SNR-50 is calculated by the Spearman-Karber equation. Normative data for children and adults are available for the original WIN test [16, 17]. In 2017, Mahdavi et al. introduced the Persian version of the WIN test named the Auditory Recognition of Words-in-Noise (ARWIN) test. They randomly allocated 105 Persian monosyllabic words collected from the reading books for primary school children into three 35-word lists. The words had been recorded by a male speaker, digitized and mixed with Persian six-talker babble (two males, two females, two children) [18]. The reliability and validity of the ARWIN test were confirmed by administering the three word lists to children with learning problems (dichotic listening deficit) and normal peers [18, 19]. Several studies have also used the ARWIN test in subjects with normal hearing [20-22] and SNHL [23]. In a study using the WIN test on patients with SNHL, the results indicated that the patients with a PTA less than 45 dB HL needed more SNR by 10–12 dB than normal-hearing peers to achieve the same level of recognition performance [24]{Wilson, 2011 #22}. We found no study using the ARWIN test in patients with moderate to severe SNHL having different audiogram configurations. This study aimed to examine the inter-list equivalency of the ARWIN word lists in clinical cases with SNHL.

Methods

Study design and participants

In this cross-sectional study, participants were 54 older adults with mild to severe SNHL levels (35 females, 19 males) with a mean age of 51.2±13 years who were selected from among the patients referred to the hearing aid clinic of Amir A'lam Hospital in Tehran, Iran, and 49 normal-hearing people (33 females, 16 males) with a mean age of 28.9±7 years, who were selected from among the students and staff of the School of Rehabilitation Sciences at Shahid Beheshti University of Medical Sciences. Inclusion criteria for the patients were the normal condition of outer and middle ears, normal score in the General Health Questionnaire-28 (GHQ-28), Mini-Mental State Examination (MMSE), and the Pittsburgh Sleep Quality Index (PSQI). Inclusion criteria for the healthy people were the normal condition of outer and middle ears, a hearing threshold≤15 dB HL at 250–8000 Hz, and obtaining normal scores in GHQ-28, MMSE, and PSQI. Exclusion criteria were unwillingness or inability to continue participation (for both groups), using any medication that could affect sleep quality, general health, emotional and cognitive states, or other drugs that may interfere with the results of the study (for normal-hearing group). The SNHL patients were divided into three subgroups based on the average hearing loss at the frequencies of 500, 1000 and 2000 Hz. The first subgroup (SG1) had a hearing loss of≤40 dB HL. The second and third subgroups (SG2 and SG3) had a hearing loss of 41–59 and 60–79 dB HL, respectively [16].

Measures

At the first step, explanations about the procedures were provided to the participants and they signed an informed consent form. In the normal-hearing group, all participants were assessed in terms of sleep quality, general health, and mental state using the PSQI, GHQ-28, and MMSE, respectively. Since these factors can affect the speech processing in noise, normal hearing people were assessed based on their results in the mentioned tests (a total score of≤5 in PSQI, 24–30 in the MMSE, and less than 23–24 in GHQ-28) [25-27]. Both otoscopy (Heine otoscope, Optotechnik Co, Germany) and tympanometry (AT235 tympanometer, Interacoustic Co, Denmark) confirmed normal condition of the outer and middle ears in both groups. Pure tone audiometry and speech audiometry were performed using a calibrated two-channel audiometer (AC40, Interacoustic Co, Denmark). The WRS in quiet was measured using a monosyllabic 25-word list at the most comfortable level using live voice [28].

In the next step, speech recognition in noise was evaluated by the ARWIN test [18, 19]. This test, like the original WIN test, has available pre-recorded separate lists. The ARWIN test materials were presented to the participants through a calibrated media player attached to the audiometer. The presentation level determines the level of multi-talker babble noise. According to the clinical protocol of the WIN test [16], the noise presentation level in the ARWIN test was set at 60 dB HL for the normal-hearing group and SG1, and 70 dB HL for the SG2. The protocol of the WIN test dose not propose any noise level for hearing losses≥60 dB HL. We presented the noise to SG3 at 80 dB HL. In 55 participants, the examined ear was the right ear (53.4%), while in 48 participants, the left ear was tested (46.6%). Finally, the number of correct words uttered by each participant was recorded, and the SNR-50 was calculated using the Spearman-Karber equation. To calculate the overall SNR-50 for each participant, the results for the SNR-50 of the three-word lists were averaged.

Statistical analysis

Collected data were analyzed in SPSS v.17 software (IBM Corp., USA). The normality of data distribution was examined using the Kolmogorov–Smirnov test. The effect of the word list in normal-hearing group was analyzed by Freedman's test and in SNHL group by repeated measures ANOVA. Comparison of the mean SNR-50 between normal-hearing and SNHL group was performed by one-way ANOVA. In all statistical tests, $p<0.05$ was considered as a significant level.

Results

The mean hearing thresholds of the normal-hearing people and SNHL patients at 250–8000 Hz frequencies are plotted in Figure 1. The mean (SD) of the SNR-50 for each list and the average of three lists are given in Table 1. The mean WRS of the normal-hearing individuals was 100%, while for SG1, SG2 and SG3 of SNHL group were 96.55±5.02, 92.84±10.96 and 76.75±26.29, respectively.

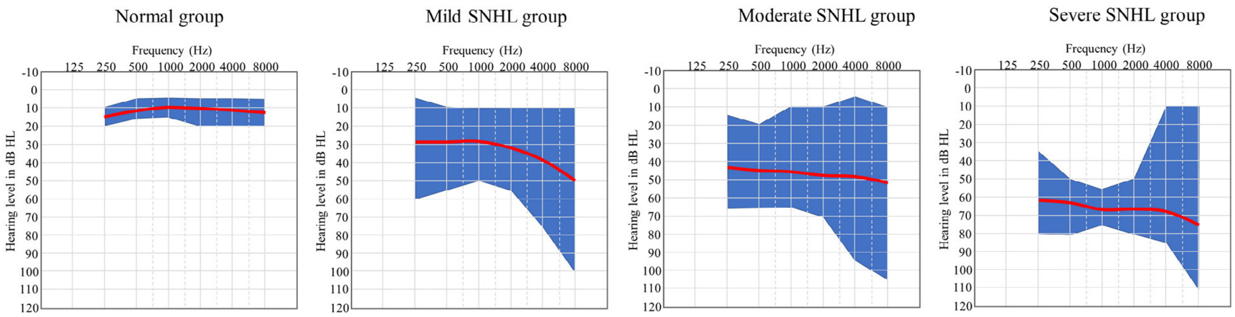

Figure 1. The range (blue area) and mean hearing thresholds (red curve) in the ears of participants with normal hearing and three subgroups of patients with sensorineural hearing loss (mild, moderate, and severe subgroups). SNHL; sensorineural hearing loss

Table 1. The mean and standard deviation of the signal-to-noise ratio (50%) for each list of auditory recognition of words-in-noise and the average of the three lists in sensorineural hearing loss groups

	List no.1	List no.2	List no.3	Average
Normal hearing	2.54±1.42	2.41±1.52	2.72±1.51	2.56±1.21
≤40 dB	10.95±5.43	9.31±4.71	10.15±4.90	10.13±4.83
41–59 dB	15.35±4.61	13.41±4.82	14.76±5.44	14.51±4.71
60–79 dB	18.25±4.01	15.42±4.83	16.15±4.64	16.61±4.32

The mean SNR-50 obtained from the three word lists in the normal-hearing group was not significantly different ($\chi^2(2)=1.76$, p=0.415). In all three SNHL subgroups, the main effect of the word list was significant. Pairwise comparison showed a significant difference in the mean SNR-50 for the SG1 between the Lists no.1 and no.2 (p<0.05). For the SG2, a significant difference was reported between the Lists no.1 and no.2 and between the Lists no.2 and no.3 (p<0.05). For the SG3, the List no.1 showed a significant difference with the other two lists (p<0.05) but there was no significant difference between the Lists no.2 and no.3.

The mean SNR-50 of the normal-hearing group had a significant difference with that of SNHL subgroups (p<0.001). The mean SNR-50 showed a significant difference between hearing loss subgroups (SG1, SG2 and SG3), ($F_{(2,51)}=8.90$, p<0.01). However, the mean SNR-50 did not show a statistically significant difference between the SG2 and SG3 (14.51±4.7 dB vs. 16.61±4.3 dB, p=0.654). As shown in Figure 2, as the degree of hearing loss increases, the mean SNR-50 increases. The correlation between SNR-50 and the mean PTA at 500, 1000 and 2000 Hz was moderate while it was strong at 500 to 8000 Hz (Table 2 and Figure 3).

Discussion

Difficulty of speech perception in noise is one of the main complaints of patients with SNHL, which can affect their quality of life and satisfaction with hearing aids. The purpose of this study was to investigate the word recognition in noise in adults with mild to severe SNHL in comparison with normal-hearing people. Although a low speech perception score in quiet is associated with poor performance in the presence of noise, a good score speech perception in quiet tests cannot predict the performance of speech perception in noise [24, 29]. The results of our study confirmed the results of previous studies. In our study, normal or almost normal WRS in SG1 and SG2 was not consistent with the SNR-50, which was approximately 8–14 dB more than that in the normal-hearing group and indicates a considerable difficulty in word recognition in noise. As expected, the mean SNR-50 of the three word lists were higher in patients with SNHL than normal-hearing subjects. In fact, these patients need a higher SNR than individuals with normal hearing to obtain the same performance of word recognition in a noisy environment. The mean SNR-50 of the normal-hearing group was 2.56 dB, which increased by about 4 times the value in the SG1 and

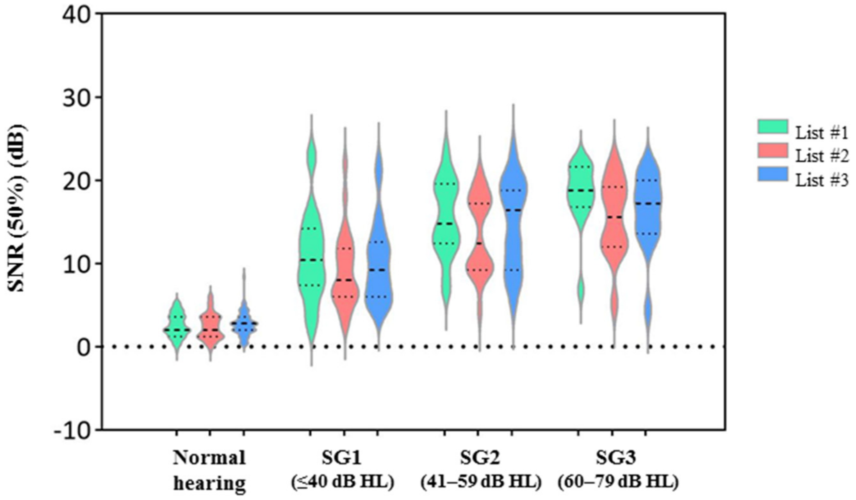

Figure 2. The violon plot of signal-to-noise ratio (50%) in three lists in each group of normal-hearing, mild (≤40 dB HL), moderate (41–59 dB HL), and severe sensorineural hearing loss (60–79 dB HL). SNR; signal-to-noise ratio, SG; subgroup

Table 2. The correlation between the signal-to-noise ratio (50%) and pure tone average. Pure tone average 1 is the average of pure tone thresholds at 500, 1000, and 2000 Hz. Pure tone average 2 is the average of pure tone thresholds at, 500, 1000, 2000, 4000, and 8000 Hz

	PTA1	PTA2
List no.1	**0.65***	**0.76***
List no.2	**0.59***	**0.70***
List no.3	**0.59***	**0.72***

PTA; pure tone average
* p<0.001

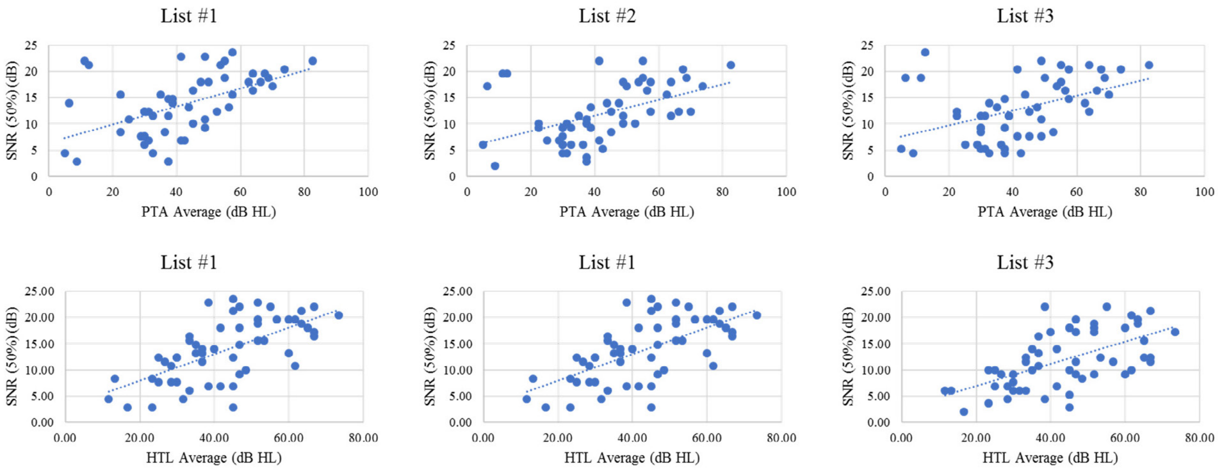

Figure 3. The correlation between signal-to-noise ratio (50%) and pure tone average. Upper plots: correlation between signal-to-noise ratio (50%) and pure tone average of 500, 1000, and 2000 Hz for each list. Lower plots: correlation between signal-to-noise ratio (50%) and pure tone average of 500, 1000, 2000, 4000, and 8000 Hz for each list. SNR; signal-to-noise ratio, PTA; pure tone average, HTL; hearing threshold level

reached 10.13 dB. The SNR-50 increased with a slower slope from 10.13 dB (in SG1) to 16.61 dB (in SG3). This finding is in line with previous studies that have examined this issue in patients with moderate-to severe SNHL [5, 12, 30]. In a study, the average SNR-50 was reported 2.7–5 dB and 15.8–9.4 dB for normal-hearing adults and SNHL patients, respectively [24]. Wilson and Burks indicated that normal-hearing individuals and adults with mild to moderate hearing loss need an SNR of 0–6 and 13.7–14.2 dB to achieve 50% of word recognition, respectively, which are in good agreement with our results [31]. In a study by Wilson et al. [12], the SNR-50 was in the range of 1–4 dB for individuals with normal hearing and 5–14 dB for patients with SNHL. The mean separation of the hearing-impaired group from normal-hearing group for the WIN test was 8–10 dB. In our study, the subgroup with a hearing loss<41 dB needed an average SNR-50 of 10.13 dB with a separation of 7.57 dB from the normal-hearing group (2.56 dB) which is in agreement with the results of Wilson et al [12]. Moreover, our findings consistent with the results of a previous study that indicated that patients with PTA less than 41 dB HL obtained the WIN 50% point at an SNR of 12 dB and had approximately 9 dB differences with normal-hearing people (2.7 dB) [32]. In McArdle et al.'s study, the mean SNR-50 for individuals with normal hearing and SNHL patients was 4.7 and 12.4 dB, respectively [10]. In a study by Plomp et al., people with mild and moderate to severe hearing losses had approximately 2.5- and 7-dB higher SNR than normal-hearing people in sentence recognition in speech-shaped noise, respectively [33].

In our study, there was a significant relationship between the degree of hearing loss and mean SNR-50 in SNHL group, but there were no significant differences in the mean SNR between SG2 and SG3; as the degree of hearing loss increased, the SNR-50 increased, indicating the worsening of word recognition in noise. The patients with PTA>60 dB HL (SG3) needed more SNR by about 14 and 6.5 dB than the normal-hearing group and SG1, respectively. Patients with more SNR loss have more difficulties in speech recognition, especially in noisy conditions. Thus, they may visit the clinic frequently for adjusting their hearing aids since they have unrealistic expectations of hearing devices for solving their problems. The WIN test score can address this problem and is clinically valuable for counseling and making better hearing rehabilitation or for hearing aid selection and fitting. It can reveal the benefits or limitations of hearing aids for patients with SNHL, especially those with severe hearing loss [1]. Smith et al. examined the SNR-50 using two competing noises (six-talker babble and single-talker competing noise) in participants with normal-hearing and SNHL and calculated by the Spearman-Karber equation. Their obtained values varied from –3.5 to 3.9 dB in the normal-hearing group and from 11.1 to 13.4 dB in SNHL group based on the selected noise [34].

The background noise level affects the SNR-50 even in normal-hearing people. In the present study, the noise level was selected according to the protocol of original WIN test; therefore, the results in cases with hearing loss were highly similar to the results of previous studies [12, 34]. We used a noise level of 80 dB HL for SG3, since there was no exact data on the clinical protocol of the WIN test for SNHL individuals with PTA above 60 dB HL. Although our finding showed significant differences between the results of the normal-hearing group and SG3, no significant difference was found between SG2 and SG3. This is maybe due to insufficient level of the multi-talker babble. In other words, perhaps the noise level was not challenging enough to create a significant difference in the mean SNR-50 of the two groups. Therefore, further studies are recommended using different noise levels for SG3 to find appropriate noise level and determine a more accurate clinical protocol to provide more SNR separation between patients with moderate and severe hearing loss.

Since the word list effect was not observed in the normal-hearing group, it can be used clinically for the normal-hearing people suspected of auditory processing disorder. However, the current word lists of the ARWIN test cannot be considered as equivalent for cases with SNHL. The researchers and clinicians should be cautious in using the word List no.1 and comparing its results with other word lists. It is recommended to use the word List no.1 as a practice list. The results of this study encourage the creators of the ARWIN test to revise it to achieve equivalent word lists.

In the current study, due to the difficulty in finding older adults as a control group, with no history of hearing loss, cognitive disorders, abnormal mental state, general health problems, and other disorders that may interfere with the results of the study, we had to select the control group from younger adults. Since some studies have indicated the effect of age on speech processing, it is recommended that this study be replicated using the similar age groups of normal-hearing and SNHL participants. The SNHL group in the present study consisted of patients with different ear pathologies and causes of hearing loss, such as presbycusis, Meniere's disease, sudden and congenital hearing loss, and noise-induced hearing loss. Similar studies are recommended to evaluate these patients' performance in noise based on these causes because different pathologies can have different effects on the auditory processing in terms of word recognition in noise. The results of the present study can help audiologists address individuals' complaints better in audiology clinics.

Conclusion

The adults with Sensorineural Hearing Loss (SNHL) need more Signal-to-Noise Ratio (SNR)-50 by about 4–6 times than normal-hearing people. With the increase of hearing loss, the SNR-50 increases; the slope from normal hearing to mild hearing loss is steeper than mild to moderate-to-severe hearing losses. The word lists of the auditory recognition of words-in-noise test cannot be interchangeably used in SNHL cases, though are equivalent when applying for the normal-hearing cases.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Research Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.RETECH.REC.1400.1233).

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

EN: Study design and acquisition of data; statistical analysis, interpretation of the results, drafting the manuscript; HJ: Study design and supervision, interpretation of the results, and critical revision of the manuscript; MEM: Study design and interpretation of the results, and validation the final revision of the manuscript; AK: Validation the final revision of the manuscript. All authors discussed the results and contributed to the final manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

The authors would like to thank all students, staff and patients for participation in this study.

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