Research Article

Is Acceptable Noise Level Affected by the Number of Competitive Talkers? An Implication of Informational Masking and Listening in Dips for Acceptable Noise Level Mechanism

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Highlights

- As the number of talkers in noise increases, the noise tolerance decreases
- Acceptable noise level (ANL) increases significantly just for fewer talkers in noise
- ANL is affected significantly by forward and backward background noises

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ABSTRACT

Background and Aim: The Acceptable Noise Level (ANL), which is an effective clinical tool for quantitative assessment of noise tolerance, is affected by some known variables related to both subject and testing materials. The present study examined how the characteristics of different babble noises may affect the ANL results in normal adult listeners.

Methods: Forty Persian listeners with normal hearing participated. In addition to typical ANL testing with 12-talker noise, the ANL was obtained in 8 different conditions varying in number of talkers from 2 to 10 in the babble noises presenting forward and backward.

Results: There was a significantly lower ANL for 2-talker babble compared to 4, 8, 10, and 12-talker babble in both forward and backward noise conditions. With the increase in talkers in noise, the ANL becomes worse but reaches almost a plateau with more than 4 talkers in babble noise. There was a statistically significant difference between 2-talker forward and 2-talker backward noises, with no difference for the other conditions.

Conclusion: This finding that the ANL is affected by the number of talkers in babble noise and by the forward and backward background noise suggests that informational masking and listening in dip mechanisms are involved in ANL for normal hearing people at least.

Keywords: Acceptable noise level; speech babble noise; listening in dips; informational masking; energetic masking

Introduction

Speech perception in noise can be a challenge in daily life, especially for elderly people who are affected by the consequences of aging on their auditory and cognitive systems [1]. People with a poor ability to understand speech in noise constantly complain of hearing fatigue, hearing sentences without meaning, and feeling uncomfortable in noisy situations [2]. Although speech perception-in-noise tests provide information about people's listening ability, speech perception is influenced by the subjects and test characteristics [3].

While most of speech-in-noise tests help clinicians evaluate speech intelligibility in the presence of noise, such as Hearing in Noise Test (HINT), Quick Speech in Noise (QuickSIN), Word in Noise (WIN), etc., the Acceptable Noise Level (ANL) test focus on the listening comfort aspect of the auditory system in noisy situations. ANL is a suitable clinical tool for quantifying the subject ability to tolerate noise. For years, hearing care professionals have focused on sound processing in hearing aids to improve speech intelligibly. However, Nebelek found out that listening comfort is another important factor for patients to accept using hearing aids [4]. Successful hearing aid users have relaxed listening without effort and experience long-term listening awareness and speech understanding in noise without fatigue [5].

Nebelek et al. introduced ANL in 1991 to be used as a part of a test battery assessment to predict the success rate of hearing aid use by the rate of 85% [5]. The finding showed that people with lower ANL have more benefits and use hearing aids than those with higher ANL [5].

ANL is not related to age, the gender of the listener, or discomfort level of hearing [6-8]. Although most studies have not found a significant relationship between ANL and pure-tone averages [5], some studies have found a relationship between the pattern of hearing loss and ANL results [9, 10]. The ANL is more related to the function of the central auditory nervous system and less influenced by the peripheral auditory system [11].

ANL results can be affected by several factors, such as individual traits, different methods in test administration, and the use of different test materials [4, 12]. Several research studies have explored the impact of using various test materials. In one of the earliest investigations, Nebelek compared the influence of drill noise, traffic noise, 12-talker babble noise, speech-spectrum noise, and music on ANL. No significant relationships were observed in various conditions except when music was used as the background noise [4]. Further studies showed that the pleasantness and unpleasantness of music used as background noise could affect ANL results [13]. In addition, the investigations about the effects of different types of target signals indicated that meaningful context and coherent speech signals are the variables that had a relationship with ANL [14].

It is important to understand the effects of different test materials on ANL results. This helps select appropriate materials for evaluating individuals' abilities in various noisy situations. A study by Gordon-Hickey et al. on the effect of different babble noises showed no significant relationship between the number of talkers in babble noise and ANL. Assessment of the ANL with varying numbers of talkers in babble noise in both forward and backward conditions was suggested to precisely understand the effect of informational and energetic masking on ANL [15].

One major factor affecting noise tolerance is the characteristics of background noise, including its temporal fluctuations, the number of talkers, and the semantic context of noise. The more similar the acoustic characteristics of noise and signal are, the weaker ANL results are obtained [15]. The presence of background noise can cause energetic masking. It happens when the energy of the background noise is greater than the speech signal, and therefore, it poses a considerable challenge to speech intelligibility [16]. However, when background noise contains fluctuations, as commonly experienced in daily situations, there is an opportunity to use listening in dip ability to glimpse the target stimuli [16]. Another factor affecting the ANL is the variables related to the language, which include noise meaningfulness, familiarity with language, and meaningful context. If the babble noise is meaningful and also has a high similarity to the target signal in terms of content, it causes high informational masking. A study used 1, 2, 4 and 8 talkers in babble noise showed the lowest ANL was in 8 talkers condition [17]. It is likely that there are different outcomes for various languages.

Furthermore, although it is mainly accepted that energetic masking occurs at the peripheral auditory system, there is some opposite view about the exact location of this masking because higher-level processing beyond the peripheral auditory system, such as binaural processing, may help release from energetic masking [18, 19]. Background noise can cause informational masking, resulting in difficulties in auditory scene analysis. Thus, unsuccessful target signal selection happens when both sounds are audible, but the target signal remains indistinguishable [20]. Challenges arising from informational masking often relate to the performance of the central auditory system, posing challenges to language processing, working memory, and auditory attention [21]. Although different temporal fluctuations in background noise provide opportunities for listening in dips, they also increase informational masking [22]. Speech babble noise as background noise can have varying numbers of talkers from one to dozens. When speech babble noise has fewer than three talkers, it causes more informational masking, whereas four or more speakers can lead to greater energetic masking [23, 24]. Multi-talker babble, which has spectral characteristics similar to non-speech noise, like white noise, can mask the speech targets [25]. Hence, Modulation has a more substantial effect when multi-talker babble involves fewer talkers and can produce different results on the ANL test than the 12-speaker multi-talker babble [25]. By creating multi-talker babble with different numbers of speakers, we can get an insight into the effects of energetic masking, and by reversing the babble noise to make non-meaningful noise, the effect of informational and energetic masking can be observed separately [15].

This research aims to evaluate the effects of energetic and informational masking on the ANL and to identify which background babble noise has the greatest and least significant influence on the ANL. The investigation considers different numbers of talkers in multi-talker babble settings, including two, four, eight, and ten talkers in two forward and backward modes.

Methods

Forty normal hearing subjects (20 males) aged 20–44 years (25.85±4.34) participated in this study. The participants were monolingual Persian selected from the students and employees of Shahid Beheshti University of Medical Sciences, Faculty of Rehabilitation Sciences, Tehran. All subjects passed the normal hearing screening test with a hearing threshold <15 dB HL at 250–8000 Hz and the normal immittance test (tympanometry and acoustic reflex). None of the participants had any history of neurological pathologies. Indeed, all participants read and signed informed consent.

Stimuli

The target signal used in this study was the recorded Persian story narrated by a female and prepared for the Persian version of ANL by Ahmadi et al. [26]. To create babble noises, female talkers were used to read different stories, resulting in the recorded 2, 4, 8, and 10-talker conversational babble noise. Then, these four noises were designed by Adobe Audition software to be used for the two main types of background noise: forward and backward background noises (FBN and BBN). In the FBN, all noises are summed up together as the normal approach applied for speech in noise tests. In BBN, all noises are played backward to create a non-meaningful speech babble noise. Finally, the primary and background stimuli created for this study were paired to create a total of eight test stimuli (four items for the FBN condition and four items for the BBN condition). Also, the original Persian version of ANL (that is, with 12-talker babble noise) was applied in this study as the typical ANL condition for comparison with the FBN and BBN conditions [26]. Noticeably, there was not any sensible difference between 12-talker forward background noise and 12-talker backward background noise in our pilot study. Furthermore, regarding the duration of running female speech in the Persian version of ANL (7 minutes) and controlling the learning effect for participants in the present study, the 10-talker babble noise was selected as the maximum number of talkers in this study. The stimuli were presented monaurally via a calibrated audiometer through TDH-39 headphones (AC40, Interacoustics Co, Denmark).

The testing was conducted in a single session, with breaks allowed as needed. During experimental procedures, all signals were played through TDH-39 headphones, utilizing an Acer Predator Helios 300 laptop connected to a clinical audiometer (AC40, Interacoustics Co, Denmark) through a 2.5 mm audio jack. The audiometer was calibrated by the American National Standards Institute code [27].

The laptop's volume and the auxiliary audiometer input were carefully adjusted to 0 volume units using a calibrated tone of 1000 Hz, which is commonly included in the ANL Persian test. This process ensures that the audio output is at an optimal level for accurate testing and analysis. All ANL tests were conducted monaurally, with signals and noise presented to the same ears. The ANL test comprises three essential steps. The first step is called the Most Comfort Level (MCL) measurement, in which a female speaker's running speech is played through headphones using a calibrated audiometer at 30 dB HL. The subject is then asked to give feedback on the speech level by hand movements. When the sound level was low and needed to be increased, it showed thumb up. If the sound level was too loud, he/she showed a thumbs down to request a decrease. If the sound level was perfect, the flat palm signal was used. Primarily, speech level either increased or decreased in increments of 5 dB. As the final adjustment approached, the step size was reduced to 2 dB to determine the exact MCL. The MCL measurement was achieved by repeating the process three times and averaging the results.

The next step involved measuring the Background Noise Level (BNL). During this stage, the female speaker's running speech was played at a comfortable level while noise was presented at 30 dB HL. Then, it gradually increased in 5 dB steps, and the participants were instructed to find the appropriate noise level to listen to and put up with the story without being interrupted or tired. The step size is then reduced to 2 dB when the final adjustment is reached. The BNL is defined as the highest level of noise that the subject can tolerate without being tense. To obtain the BNL measurement, the process was repeated three times, and the average was taken.

The final stage was to measure the ANL, which was calculated by subtracting the BNL from the MCL (ANL=MCL–BNL). Under monotic listening conditions, ANL measurements were taken for five different noises. The testing duration for each participant was approximately 60 minutes. Various listening conditions were tested randomly for every subject, and several breaks were provided.

Statistical analysis

All data from the study was analyzed using SPSS software (v.17.0) (SPSS Inc., Chicago, IL, USA). The analysis included descriptive statistical parameters such as means, standard deviations, and ranges of MCL, BNL, and ANL results. 8 variations of ANL were tested (2, 4, 8, and 10-talker babble noise in forward and backward conditions). In addition, as a reference condition for comparing with the above conditions, the typical ANL, which is accompanied by 12-talker babble noise, was tested as well. The data distribution was assessed to be normal using the one-sample Kolmogorov-Smirnov test. To compare within-subjects, a repeated measure analysis of variance (ANOVA) (Greenhouse-Geisser) was conducted. For pairwise comparisons, Bonferroni correction was used. $p \leq 0.05$ was statistically significant.

Results

The ANL ranged from –11 to 0 dB. The means and standard deviations for ANL have been presented separately for each condition in terms of both the right and left ear in Table 1. Also, the averages of both ears are calculated as overall in Table 1.

To examine the effect of different types of noise on the results of the ANL test in the left and right ears, a repeated measures ANOVA with two within-subject factors was utilized. One factor represented the left and right ears, while the other represented the noise type. Based on the obtained results, comparing the effect of noise type between the left and right ears showed no significant difference ($p=0.057$). Furthermore, in the ANL results obtained, no significant interaction was observed between the right and left ears for different background conditions ($p=0.724$). This implies that increasing and decreasing ANL across different noise types is relatively similar in both ears.

Considering that no significant difference was observed between the left and right ears in comparing ANL with different types of noise, the ANLs for right and left ears pooled together, as shown in Figures 1 and 2 for forward and backward background noise conditions, respectively. In both Figures, the lowest ANL was found when the competitive noise was 2-talker babble noise, a fact that is observed for both conditions of forward and backward noise (–5.41 and –5.97 dB for forward and backward background noise conditions, respectively).

The repeated measures ANOVA was employed, specifically comparing the effect of noise in different

Table 1. The acceptable noise level mean and standard deviations for four conditions (2, 4, 8, and 10-talker) in both forward and backward noises in terms of right ear, left ear, and overall (average of both ears). For comparison, the mean and SD of acceptable noise level for typical acceptable noise level testing performed with 12-talker babble noise is provided in the right side.

		2 Talkers	4 Talkers	8 Talkers	10 Talkers	12 Talkers
Forward background noise	RE	–5.25±1.91	–4.50±1.56	–4.37±1.76	–4.37±1.65	–3.95±1.46
	LE	–5.57±2.06	–4.90±1.75	–4.27±1.61	–4.75±1.83	–4.17±1.41
	Overall	–5.41±1.98	–4.70±1.66	–4.33±1.68	–4.56±1.74	–4.06±1.43
Backward background noise	RE	–5.92±1.67	–4.72±1.50	–4.65±1.47	–4.37±1.80	–3.95±1.46
	LE	–6.02±1.73	–5.07±1.26	–4.45±1.37	–4.65±1.42	–4.17±1.41
	Overall	–5.97±1.69	–4.90±1.39	–4.55±1.42	–4.51±1.62	–4.06±1.43

RE; right ear, LE; left ear

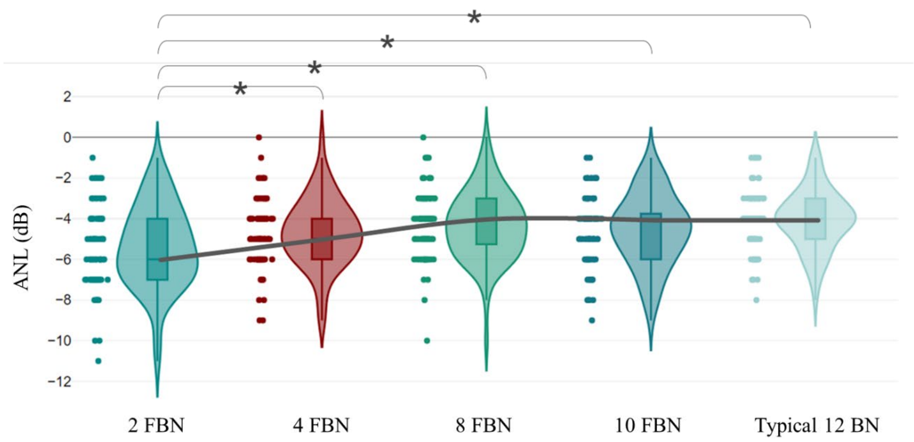

Figure 1. The violin plots for acceptable noise level in four conditions of forward noise (2, 4, 8, and 10-talker) and typical testing with 12-talker noise. The medians are connected by a grey line to show the trend. 2 FBN: 2-talker forward noise, 4 FBN: 4-talker forward noise, 8 FBN: 8-talker forward noise, 10 FBN: 10-talker forward noise, and typical 12 BN: typical testing approach with 12-talker babble noise. ANL; acceptable noise level, FBN; forward background noises

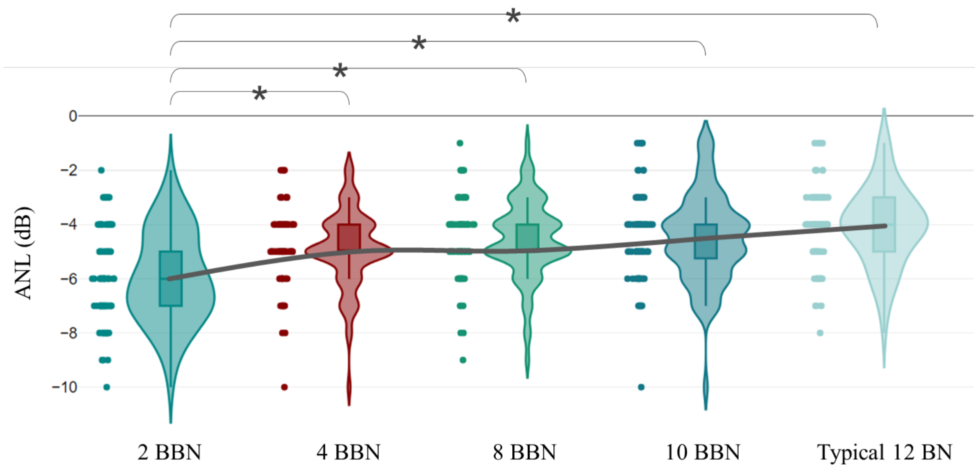

Figure 2. The violin plots for acceptable noise level in four conditions of backward noise (2, 4, 8, and 10-talker) and typical testing with 12-talker noise. The medians are connected by a grey line to show the trend. 2 BBN: 2-talker backward noise, 4 BBN: 4-talker backward noise, 8 BBN: 8-talker backward noise, 10 BBN: 10-talker backward noise, and typical 12 BN: typical testing approach with 12-talker babble noise. ANL; acceptable noise level, BBN; backward background noises

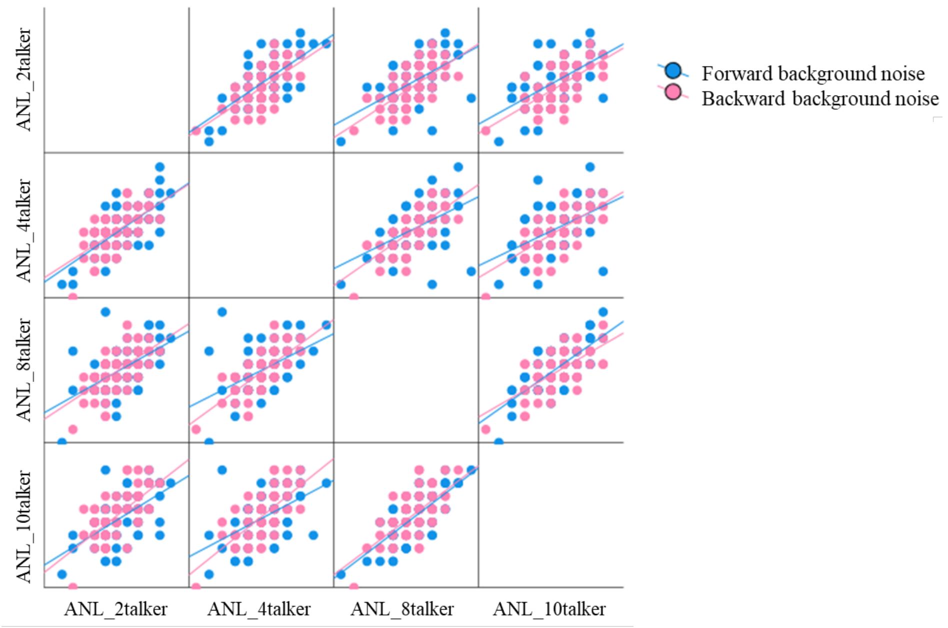

Figure 3. The scatter plots of acceptable noise level for all eight tested forward and backward conditions. The blue and pink data are for forward and backward background noise conditions, respectively. The fit line is shown for each condition with the dedicated color, as well. ANL; acceptable noise level

Table 2. The acceptable noise level correlation between various forward and backward background noise conditions. 2 FBN: 2-talker forward noise, 4 FBN: 4-talker forward noise, 8 FBN: 8-talker forward noise, 10 FBN: 10-talker forward noise, 2 BBN: 2-talker backward noise, 4 BBN: 4-talker backward noise, 8 BBN: 8-talker backward noise, and 10 BBN: 10-talker backward noise

	2 FBN	4 FBN	8 FBN	10 FBN	2 BBN	4 BBN	8 BBN	10 BBN
2 FBN		0.68**	0.55**	0.58**	0.73**	0.66**	0.62**	0.66**
4 FBN	0.68**		0.50**	0.50**	0.54**	0.67**	0.54**	0.59**
8 FBN	0.55**	0.50**		0.73**	0.59**	0.66**	0.69**	0.57**
10 FBN	0.58**	0.50**	0.73**		0.55**	0.57**	0.58**	0.62**
2 BBN	0.73**	0.54**	0.59**	0.55**		0.65**	0.65**	0.67**
4 BBN	0.66**	0.67**	0.66**	0.57**	0.65**		0.71**	0.69**
8 BBN	0.62**	0.54**	0.69**	0.58**	0.65**	0.71**		0.66**
10 BBN	0.66**	0.59**	0.57**	0.62**	0.67**	0.69**	0.66**	

FBN; forward background noises, BBN; backward background noises
** p<0.001

conditions. The results indicated that the noise type significantly impacts ANL test outcomes ($p<0.001$). Pairwise comparisons of ANL results with different types of noise using the Bonferroni method are demonstrated in Figure 1 and Figure 2. Adjusted Bonferroni correction comparing the different numbers of talkers in speech babble revealed that for both forward and backward conditions, although there was a significantly lower ANL just for 2-talker babble condition when compared to 4, 8, 10, and 12 talkers babble, no significant difference was observed between other conditions (Figures 1 and 2).

Furthermore, when comparing the forward noise conditions with backward noise conditions, the statistical analysis showed that there is statistically significant difference just for 2-talker noise conditions (–5.41 and –5.97 dB for forward and backward conditions, respectively, $p<0.012$).

The scatter plots for all conditions of forward and backward noises are shown in Figure 3. The Pearson correlation showed that there is a statistically significant moderate correlation between all conditions together ($p<0.001$, Table 2). However, there is a moderate correlation (0.5–0.73) for all conditions.

Discussion

This study examined the impact of different babble noises on ANL. Results showed that ANL was significantly lower with two talkers' background noise. As the number of talkers increased, noise tolerance decreased for both forward and backward noise conditions. This might be because of the mechanism of ANL that relies on the ability of listening in dips at least in normal hearing adults, which depends on the number of gaps in the noise. Fewer talkers in babble noise mean more gaps and fluctuations, making it easier to receive the speech signal. With an increase in the number of talkers, the gaps in the noise start to decrease, and the noise has fewer spectro-temporal fluctuations. Consequently, the auditory system is no longer able to easily receive the speech signal, resulting in a higher ANL in noises with a larger number of talkers.

Even though our finding shows that ANL is affected by the number of talkers in babble noise, it appears that the ANL differences between conditions with fewer talkers are more significant and diminish when the number of talkers increases until it reaches a plateau. The results of our study demonstrate that ANL changes decrease progressively up to 4-talker babble noise, with no significant difference between ANL outcomes with 4-talker babble noises and more. Our interpretation is when the number of talkers in babble noise increases, the existing gaps in the noise are eliminated gradually. Gordon-Hickey and colleagues, examining the effects of different noise conditions with different numbers of talkers, did not find significant differences between the various conditions [15]. This finding was not aligned with our results. However, it was observed that the differences in ANL between 1-talker and 4-talker babble noise are greater, and the slope of the change decreases as the number of talkers increases.

Consistently, the pairwise comparisons of different conditions revealed that 4-talker noise did not significantly differ from 8-talker noise [4], and the trend and magnitude of ANL change decreased with increasing the talkers. In addition, significant results were obtained only for conditions of 1 and 2 talkers.

Another finding from our study, which compares the effects of noise both in forward and backward conditions to evaluate the effects of meaningfulness of background noise showed that the pattern of ANL change is similar in these two noisy conditions. The presence of this pattern in the backward condition, where the noises are non-meaningful, suggests that energetic masking has a greater effect than informational masking and that listeners mainly benefit from the dip listening. With an increase in the number of talkers, spectro-temporal dynamics and perceptible segmental cues decreased, leading to reduced informational masking but increased energetic masking [28]. It is also believed that fine structural cues in the created streams due to temporal fluctuations are accessible with fewer talkers in the noise, but with an increase in the number of talkers and a decrease in fluctuations, these cues become obscured [29]. Our results indicate that the ANL in the 2 BBN condition is significantly lower than in the 2 FBN condition. In these two conditions, the effect of energetic masking is equal because of the similar spectro-temporal fluctuations and gaps, and only the informational masking and noise intelligibility factors were examined. There is the highest level of informational masking in the two-talker babble noise and the lowest level of energetic masking compared to other conditions. Therefore, the pairwise comparing forward and backward conditions showed that, in addition to the ability of listening in dip, informational masking can also have a significant impact on ANL.

Although the comparison results show significant differences in some conditions, it should be considered that these differences are clinically negligible. Furthermore, correlations between different conditions indicate a moderate correlation. This means that in clinical settings, the use of each noise does not make a significant clinical difference.

Contrary to our study's findings, the ANL results from the Korean research showed that with an increase in the number of talkers in noise, the ANL decreased, and the most challenging condition for ANL is in 2 talkers babble noise [17]. This discrepancy might be due to two reasons. First, it could be the phonological structure differences between the Korean and Persian languages. Korean, compared to Persian, has a different intonation pattern, and each language has specific pronunciations and stress on words. Hence, the mechanism of ANL may be different between languages. Second, the speech babble noise used in their study was a coherent and meaningful story extracted from a newspaper. When fewer talkers in noise, it makes it more intelligible to listeners. The coherence and meaningfulness of noise pose a greater challenge for attention and cognitive systems, making the process of release from informational masking harder. However, in our study, the noises included meaningful but non-coherent disconnected sentences, reducing the challenge for participants in perceiving the speech signal.

One critical aspect that should be considered when discussing the ability of listening in dips is the number of gaps present in the noise, which provide glimpses to perceive part of speech signals and the central auditory system using auditory closure to complete the fragmented speech. Previous studies have not set a standard to demonstrate this factor. As a result, listeners in two different studies with the same number of talkers in babble noise may experience different levels of difficulty due to variations in the speed rate of the target presentation and the number of gaps in the background noise. Therefore, having a standard index for ANL material would be helpful in comparing results. In the current study, the speech signal was presented at an average rate of 162 words per minute, and about 62 words (either entirely or partially) were not masked by noise. On average, the sum of these gaps were 3 seconds and 210 milliseconds in one minute.

The present study was accomplished on normal-hearing young adults. As a result, the implications of our findings may not be generalizable to populations of hearing-impaired listeners or different age groups. Because elderly people, relative to young people, benefit less from listening in dips and cognitive abilities, further studies can help to find out what factors are associated with ANL. Indeed, because a few previous studies found that the different patterns of hearing loss may affect the result of ANL [10], we suggest the assessment of ANL in different conditions in the hearing-impaired population.

Conclusion

The different babble noises can affect the Acceptable Noise Level (ANL) with the different number of talkers in forward and backward conditions. With the increase of number of talkers in babble noise, ANL becomes more difficult. It seems that listening in dips and informational masking play a vital role in ANL, at least for normal hearing people.

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.1402.219).

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Authors' contributions

MT: Study design, 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: Interpretation of the results and validation of the final revision of the manuscript; AAB: Statistical analysis.

Conflict of interest

The authors declare that there is no conflict of interest to be reported.

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