Research Article

Development and Psychometric Evaluation of Persian Dynamic Spatial Quick Speech-in-Noise Test in Adults with Normal Hearing

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Highlights

- Developing Persian version of the dynamic spatial-quick speech in noise
- Designing the dynamic spatial-quick speech in noise software
- Spatial auditory processing in people with difficulty in speech understanding

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ABSTRACT

Background and Aim: Spatial hearing is a prerequisite for the proper function of the listener in complex auditory environments. In the present study, a Persian version of the dynamic spatial-quick speech in noise (DS-QSIN) has been developed with respect to all possible factors affecting the test and to run five lists for normal hearing subjects and assessment of reliability.

Methods: To construct five new lists according to the original quick speech in noise (QSIN) test, we used frequent, familiar, and difficult words to construct unpredictable sentences. After determining the content and face validity of the sentences, 30 selected sentences were played using a DS-QSIN software for 35 subjects aged 18–25 years. The reliability of the test was assessed after repeating the test after two weeks.

Results: According to expert judges, these 30 sentences showed acceptable content and face validity with the changes. The average signal-to-noise ratio (SNR) loss of five lists was –5.2 dB. No significant difference was seen between men and women in all lists. The results indicate no difference in the average SNR loss between the five lists. Regarding the reliability assessment, the test-retest correlation coefficient was 0.5 to 0.7 ($p<0.05$). The intra-class correlation coefficient between test-retest was statistically significant ($p>0.001$) and confirmed that the lists have high reliability and repeatability.

Conclusion: DS-QSIN test showed good validity and reliability and can be helpful in diagnosis and selecting the best method for rehabilitation of people with a spatial hearing disorder.

Keywords: Quick speech in noise test; signal to noise ratio loss; dynamic spatial noise; equivalency; reliability

Introduction

In most auditory environments, our hearing system has to process complex stimuli to extract the relevant information. Listening to speech in a noisy environment is an example, i.e. a complex task that required cognitive skills (such as attention and memory) and recognition. In this condition, the central nervous system has to separate between target sound and competitive noise [1, 2]. The frequency and spatial cues help individuals to understand speech in noise. A person might have a normal auditory ability based on pure-tone audiometric tests but shows some speech recognition problems in a noisy environment. This defect might suggest a hidden central disorder. The prevalence of auditory processing disorder (APD) in children is still unknown. Previous estimations of the prevalence of APD in the general population varied widely from 0.5% to 10% [3, 4]. In children, the reported prevalence is about 3% to 5%, although some speculate that APD is over-diagnosed [5]. This value was 23% to 76% in patients aged 55 years or older [6].

Spatial auditory processing plays an essential role in speech recognition in complex auditory environments [2] because it enables the listener to localize the target sound source, and subsequently, separate the sounds based on their spatial position [7, 8]. Therefore, auditory spatial processing plays an essential role in the auditory scene analysis, during which a single auditory object or auditory stream is developed and separated from the background noise [1]. Difficulty in understanding speech should be considered one of the most incapacitating elements of hearing impairment, given its potential to cause feelings of isolation and relationships in adults [2]. Also, children with this kind of problem could have symptoms like distractibility or insufficient attention, which cause severe problems in their communication and education [9].

The quick speech in noise (QSIN) test is one of the tests related to assessing the central auditory system and, by some modifications, can be utilized as a helpful tool for the evaluation of spatial auditory function [10]. The QSIN test was introduced by Etymotic Research, Inc., in 2001. The English version of the test includes 18 lists with six sentences in each from the Institute of Electrical and Electronics Engineers sentence database. These sentences are designed to provide limited contextual cues to perceive the sentence [11].

The QSIN test provides a simple speech in noise test that can calculate the minimum signal to noise ratio (SNR) at which a listener can correctly indicate 50% of the words in the presence of four-talker babble noise. The words in sentences are grammatically correct, but the quality of content is low. There are six sentences composed of five keywords in each list provided with the preset SNRs of 20, 15, 10, 5, and 0 dB; the intensity of the target sentence was set at 70 dB HL, and the SNR decreased in 5 dB steps. The listener's task is to listen carefully to the sentences and repeat them. Each correctly repeated keyword is awarded one point for a total possible score of 30 points per list [12]. The score is determined by the formula: SNR loss = 25.5 – total word [13].

In a study, researchers designed the spatial version of the QSIN test to evaluate an individual's ability to use spatial and binaural cues for speech understanding [14]. In Iran, several tests have been designed and developed to assess spatial hearing (localization, orientation, etc.) [15-17], but the evaluation of spatial hearing in a dynamic form is a subject that has not been paid much attention in these years. A test that can evaluate dynamic spatial hearing impairment quickly could help diagnose and explain the problem precisely. This test would enable us to assess lateralization, localization ability, and benefits from separating a signal source from noise. Therefore, the current study aimed to build a Persian version of the dynamic spatial (DS)-QSIN test to develop the related software and lists. The test was conducted dynamically in normal individuals, and the reliability of the test was evaluated by running the test after two weeks.

Methods

The test was conducted on 35, 18–25 years old people (17 males and 18 females) with normal hearing with education levels from diploma to bachelor's degree. Otoscopic examination and Immittance acoustic test were performed after obtaining consent from subjects for the test. After being assured of their healthy normal conductive system, pure-tone audiometry was carried through the air conduction from 250 to 8000 Hz. The study subjects had normal hearing (average pure tone thresholds less than 25 dB) and were right-handed (according to the Edinburgh Questionnaire). For the test, the experimenter fills the questionnaire for the patient to be eligible for the inclusion criteria. The exclusion criteria if the person could not participate in a study if there is a history of head trauma, neurological diseases, or any conductive disease. All participants had no experience in music-related fields.

Initially, for constructing sentences, the words were selected according to the main target of the QSIN test. The words were chosen out of common and high-frequency words in the daily speech of native Persian speakers. All

of the length and the words used in sentences are high-frequency words available in the Farsi linguistic data database (FLDB). Assi has created a database on the Internet by gathering 50 million words from Persian poetry and prose [18]. This database offers a high-frequency word list consisting of 14000 frequent words in the Persian language [19]. For making the lists balanced, the words with low, medium, and high frequency were distributed equally in five lists. To prevent any disturbance in auditory memory, the total number of words in a sentence was not more than 7–8 words, and all words had at most four syllables [20].

To reduce the predictability and level of guessing at keywords, the cohort size of two-syllabic words from the FLDB database was calculated. Words with a cohort size of less than three were excluded, and some two-syllable, familiar, and high-frequency words with a cohort size of more than four were selected. For evaluating the predictability level of the sentence, the n-gram statistical model was used. The sentences with low perplexity are highly predictive. So based on the Persian language sentence with perplexity among 200 to 500, the sentences with perplexity lower than 300 were excluded [18].

To determine the content validity of the test, several selected sentences were scored as 0–100 by ten experts in Audiology and Speech-Language Pathology based on some criteria, including 1) familiarity and frequency of occurrence of the keywords, 2) meaningful sentences and grammatical accuracy, 3) unpredictability of the sentence based on the context and content, 4) similarity of the sentences to the daily speech, and 5) the difficulty level of the sentences. Then, to determine the face validity of the test, the sentences were judged based on the difficulty level and everyday usage in real life by some young adults with normal hearing with education level from diploma to a bachelor degree. After the balanced distribution of the sentences based on frequency of keywords among five lists, 30 sentences were chosen to be recorded in a studio by a male voice actor with a native Persian speaker, close to the dialogue speech used by average Persian speakers.

MATLAB (DS-QSIN) software was used to create a sense of spatiality and the dynamization of each list using stimulation headphone and considering data related to the binaural head-related transfer function (HRTFs) of spatial locations of the 0 azimuth value. In this regard, the sentences were presented in a spatial and moving away from the + 90 degrees (right ear) and ended to the –90 degrees (left ear), as if the signal source has been moved at a 1-m distance on a semicircle route, and the noise source (which was converted to a spatial source using DS-QSIN software) was fixed on both sides of the body at a ± 90 degrees. Hence, this test has divided each sentence into five temporal parts: each part was started at an azimuth from one ear and increased with a 45-degree value to finally reach another ear (in a moving way).

DS-QSIN software comprises two components: code view and design view, both implemented by MATLAB R-2020b software with 1385 line-based coding and EXE file for Microsoft Windows. This software requires MATLAB R-2020b software to be installed and run. The design view is developed in MATLAB App Designer, and the items and pictures were designed using MATLAB software to design the graphical interface and Photoshop CC software (Figure 1).

After the development and design of DS-QSIN software, the recorded sentences were imported to an audio processing section in the software. It should be noticed that the audio output generated by the software was transferred using a Mono Male/Stereo Female Adapter to the connection cable for earphone TDH-39. Meanwhile, in the software, the intensity of signal and noise can be changed in a calibrated way, and also, the changes of the output sound were calibrated using a sound level meter (SLM, B&K, 2250L) and 6CC coupler. To calibrate the intensity of output sound, firstly, the headphones were connected to a 6CC coupler being inserted into the SLM. Then, the sentences and the noise were played with different intensity levels, and the real-time number in the SLM was recorded. Finally, the error correction model was calculated, and the difference was used for the correction coefficient applied in the software. After the development of the test, the pilot test was conducted on 35 people (17 males and 18 females) with normal hearing. This test was performed at a comfort level (70 dB HL) for subjects.

Given the higher levels of attention and cooperation the clients showed at the start of the test, more points might be obtained in the initial lists, or, probably, the education and familiarity shown with the test in the last lists resulted in the increased patients' score in the following lists. These factors could generate some errors when the lists were balanced. Therefore, the lists were randomly provided to subjects aimed to remove the noted factors.

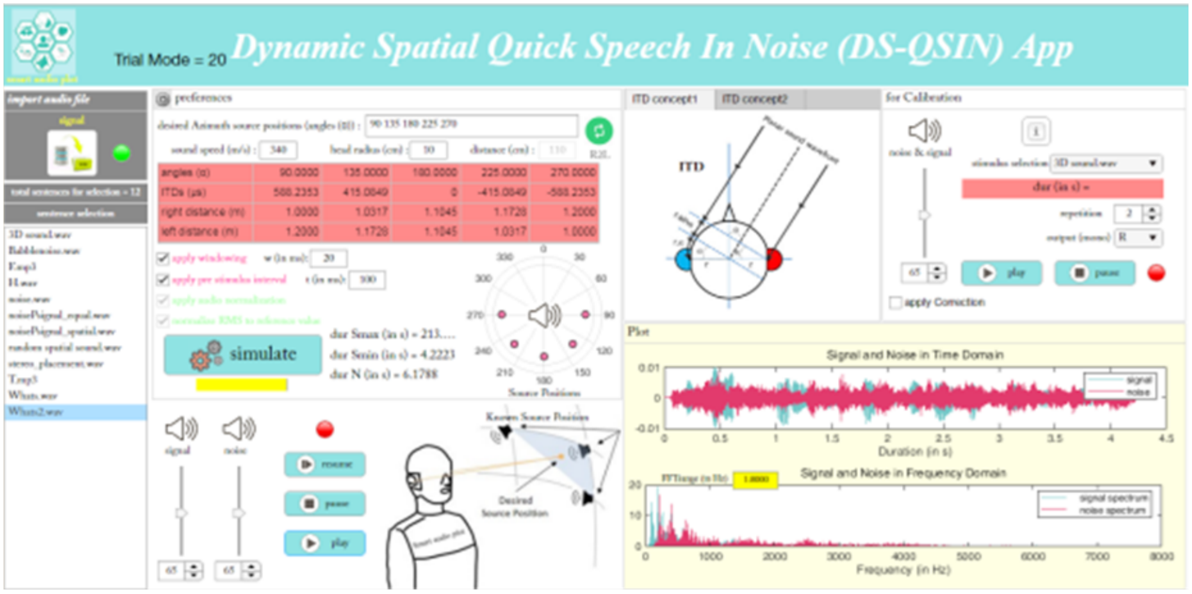

Figure 1. Dynamic spatial quick speech in noise software

After the performance of the test, the number of correct words for each list was calculated, and the SNR loss was obtained. The score of the DS-QSIN test was formulated for each language as SNR loss=17.5–the number of correct words–SNR-50 (SNR-50=–6.5 for the Persian version of spatial QSIN test) [16].

The score differences among the five lists were calculated for each individual. Two-way ANOVA was used to compare the mean scores and to evaluate the equality of five lists. The Pearson test was used to determine the correlation between pair lists. Finally, the effect of gender on the results was evaluated for each list using an independent t-test. For reliability analysis, the test was performed again two weeks later with similar subjects under the same conditions. To evaluate the reliability, the correlation coefficient and intra-class correlation were calculated. The analysis of the results was done in SPSS 16.

Results

The SNR-50 value in the Persian language and the spatial version of the test is –6.5 dB which should be applied in the SNR loss equation [16]. The mean score of each list was represented in general and for men and women separately in Table 1. The mean score of five lists was nearly the same. The mean SNR loss score of each list in the original QSIN test ranged between 0 and 3 dB. The difference in the results obtained in the DS-QSIN test can be explained by its spatial and dynamic nature.

The results obtained from comparing scores of five lists using Two-way ANOVA showed that five lists have no significant differences regarding their participants (p=0.83). In Two-way ANOVA analysis, the interaction between lists and sex was significant ($F_{(4,132)}$=0.4, p=0.017), but sex alone had no significant effect

Table 1. Mean and standard deviation signal-to-noise ratio loss of five lists in total population and comparison of the scores in men and women

	Mean (SD)			95% confidence interval of the difference		
List	Total (n=35)	Female	Male	Lower bound	Upper bound	p
1	1.5 (2.0)	1.7 (1.1)	1.2 (2.6)	−1.8	0.9	0.4
2	−1.2 (1.9)	−1 (1.5)	−1.4 (2.2)	−1.7	0.8	0.1
3	−2.2 (1.8)	−2.3 (1.8)	−2.1 (2.0)	−1.2	0.8	0.7
4	−2.1 (1.9)	−2.3 (1.7)	−2 (2.0)	−1.6	0.9	0.5
5	−1.1 (2.0)	−1.7 (2.0)	−0.6 (2.2)	−2.5	0.3	0.7

Table 2. Correlation coefficient between pair of list

List	List 2		List 3		List 4		List 5	
	Pearson coefficient	p	Pearson coefficient	p	Pearson coefficient	p	Pearson coefficient	p
1	0.5	0.007	0.4	0.03	0.3	0.1	0.5	0.001
2			0.3	0.08	0.2	0.2	0.4	0.006
3					0.2	0.2	0.6	0.001
4							0.5	0.003

(F(1,24)=0.1, p=0.34). The correlation results between the pair list are presented in Table 2.

The effect of gender on results can be seen in Table 1. There is no significant difference between men and women in their performance (p>0.05).

A comparison of the average score of test-retest for each list is presented in Table 2. The correlation coefficient found between the lists is shown in Table 3. The results suggested that the test-retest correlation coefficient was statistically significant (p<0.001). The correlation coefficient for lists 1 and 3, lists 2 and 5, and list 4 were 0.5, 0.6, and 0.7, respectively. The intra-class correlation coefficient (ICC) in the first and second tests was highly significant for all five lists (p<0.001).

Discussion

The stimulus used in the speech perception in noise tests can directly influence the nature and difficulty of the test and affect participants' performance; thus, the stimulus should be selected with much precision [20]. Both selection of keywords and the construction of unpredictable sentences constitute an essential step in developing a survey. The target population for the test performance should also be considered. Therefore, these keywords should be common in real-life speech. In the QSIN test, words are selected among common daily words. In addition, the selected words are assessed based on the difficulty level and predictability. The cohort model is a theory about speech perception. According to this theory, the similar word options to each word can be calculated and called a cohort number. Based on the cohort model when the sentence in noise tests are constructed, the lexical difficulty of words affect the difficulty and accuracy of the developed test. Word prediction plays a role in better speech understanding. It is better to evaluate speech in noise recognition with more unpredictable words (with a larger cohort size). Therefore, because of the subsequent reduction of texture cues, the subjects focus their attention on the main word, not the assumed word based on the heard initial syllables. In the present study, the cohort size is calculated based on the initial syllable of two-syl-

Table 3. Correlation coefficient between score of test and test-retest reliability coefficient values in normal individuals (n=35)

List	Pearson correlation between test and retest	p	Measurement	Inter class correlations	F	95% confidence interval		p
						Lower bound	Upper bound	
1	0.5	<0.001	Single measures	0.5	3.8	0.18	0.7	<0.001
			Average measures	0.6		0.6	0.8	
2	0.6	<0.001	Single measures	0.6	1	0.4	0.8	<0.001
			Average measures	0.8		0.53	0.9	
3	0.5	<0.001	Single measures	0.5	1.3	0.2	0.7	<0.001
			Average measures	0.7		0.3	0.8	
4	0.7	<0.001	Single measures	0.6	1	0.4	0.8	<0.001
			Average measures	0.8		0.6	0.9	
5	0.6	<0.001	Single measures	0.6	1	0.3	0.7	<0.001
			Average measures	0.7		0.4	0.8	

lable words. In addition to the frequency of words, the familiarity of the word affects word recognition. Thus, the familiar words to the listener are recognized more efficiently and faster [21]. Predicting words by hearing their first syllables can help listeners perceive speech better in a complex routine auditory environment. When the cohort size of words is known, it is easy to find some unpredictable words that can be used to construct a sentence [22]. The used stimulus in a speech in noise perception can directly affect the nature and difficulty of a test; thus, a stimulus should be selected carefully. Many studies support the hypothesis that the beginning of the word (the first 1500 ms), especially the first syllables, is vital in producing and using the cohort model. Behavioral cues indicate that the initial part of a word is crucial in word recognition [23].

The main factor in the construction of test sentences is the control of the unpredictability of the sentences. In the first step, the predictability of the sentences is measured by specific software. Then, the content validity of the sentences is judged by professionals. Next, the validity of the selected modified sentences was measured again. Test validity is another influential factor for evaluating a new test. The present study aimed to determine the content validity meaning whether or not all of the effective criteria in the test have been considered in the developed sentences. In other words, if all effective factors involved in the construction of the survey sentences have been considered or not. The relevant professionals judged the test validity, and their comments were applied to determine the content validity of each sentence based on the mentioned five effective factors. For face validity, instead of the content and nature features of the sentences, the apparent features of the test, such as acceptability and reasonableness of the sentence for subjects, are considered. Face validity is determined mainly based on the judgment of listeners and test subjects. As the test was developed for adults with a usual and average level of education, the test forms were given to some young people with the diploma and bachelor's degree to determine the face validity of the questionnaire. Because an agreement was observed among readers of the sentences regarding their level of simplicity and comprehensibility, the constructed sentences have good face validity, too.

The normal range of SNR loss is about 0 to 3 in English QSIN. In this study, the average SNR loss of 5 lists in 35 people with normal hearing was –5.2 dB. According to Etymotic Research, Inc., the mean SNR loss was 1.9 dB based on the available lists of the original test on normal hearing subjects. This value was –1.5 dB in Khalili et al. study. They used 4 Persian lists on 36 young adults with normal hearing [24]. The ability of an auditory process in young adults with normal hearing suggested that they used the spatial cues more. Brown et al. mentioned that spatial auditory processing could improve SNR to 12 dB [25]. Presenting sentences in a dynamic spatial manner could improve masking release and help people perform better in noisy situations. The differences observed in various studies for similar lists could be related to the high variability of speech recognition in noise tests. The high dependence of these tests on individual and cognitive factors is beyond doubt. The change of female speakers into the male ones and the use of easier sentences resulted in the changing value from 2 dB to –3 dB in individuals with normal hearing, even with similar babble noise. Central auditory processing, including speech recognition in noise, depends on individual's differences in the cognitive function instead of their auditory function [22]. Moreover, many studies have suggested that individuals with similar hearing thresholds perform differently in speech recognition tasks. Despite these factors, the difference in languages is essential. The Persian language is full of redundancy and content cues so despite all efforts to control the predictability of the sentences, the simplicity of them could be a possible reason for the difference between scores. Making meaningless sentence is against the rules of QSIN test so in Persian language it is not possible to have completely unpredictable sentences. The Amount of SNR-50 in different languages and even between the original and spatial versions of the QSIN test should be considered. In the English version, this value is found 2 dB [25]. SNR-50 in a shayanmehr et al. study was found 0.35 dB [19]. In the present study, this value was considered –6.5 dB based on the previous studies under similar conditions [16]. SNR Loss formula used for DS-QSIN was:

SNR loss=17.5–the number of correct words–(–6.5).

After evaluating the equivalence of five lists using Two-way ANOVA, no significant difference was found by comparing pair lists. The Pearson correlation coefficient revealed a relatively acceptable correlation between the lists used in the test. However, the limited sample size could be a reason for the low correlation coefficient. The differences between some lists are not clinically significant. McArdle and Wilson study about the equivalency of 18 lists of English QSIN showed that only nine lists are equivalent [26].

The effect of gender on the study results shows no significant difference between the sexes ($p>0.05$). Since there have been no studies about gender effect on the English version of the QSIN yet, we mention some studies about gender effect on speech in noise tests. Calais et al. investigated the effect of gender on the SPIN test results. The participants were 49 older adults (43 women and six men). The difference found between the results was not statistically significant among men and women [27], but Wiley et al. examined speech recognition on 3189 subjects aged 48–92 years using the NU-6 test. They found that the performance of recognition was better in women [28]. Gender effect on the five lists of the Persian version of QSIN was not significant to expect in list 4 [19].

When the test reliability was evaluated using two different analyses, it can be concluded that these test-retest results were better than those of the original test, probably for cognitive factors and learning effects [29]. In addition, according to Table 3, there is appropriate reliability and repeatability in the test, and a strong correlation is observed between the average SNR loss values in the test-retest. In other words, when there is a 99% confidence interval and an error of less than 1%, a remarkable relationship exists between the two variables in the test-retest.

Conclusion

The speech perception tests play a crucial role in estimating the effectiveness of communication and planning and evaluating rehabilitation functions. The dynamic spatial-quick speech in noise test is considered the only developed Persian test to evaluate the subject's hearing in a dynamic spatial form in a condition similar to daily life. The test was highly dependent on personal cognitive factors, so it was not possible to accurately study the cognitive aspects and memory of the subjects because of some limitations imposed by the COVID-19 pandemic. Moreover, utilizing some central spatial tests at the same time could have helped us for confirming our results. Generally, the present study can help professionals to optimize the evaluation of spatial auditory processing in people with difficulty in speech understanding. This opportunity could be a starting point for using this software more often in clinical and academic settings for assessing central auditory processing systems more comprehensively.

Ethical Considerations

Compliance with ethical guidelines

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Authors' contributions

MA: Study design, analysis of the results and writing the manuscript; FM: Study design, stimulus preparation, data collection, interpretation the data and writing the manuscript; SJB: Critically revising the manuscript; AAB: Analysis of the results.

Conflict of interest

The authors declared no conflicts of interest.

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