Research Article

Determining Frequency Importance Function for Speech Intelligibility of Persian Monosyllabic Words and the List of Quick Speech in Noise in Persian Language

Seyyed Mohammad Reza Taghavi[1], Ghassem Mohammadkhani[1*], Nematollah Rouhbakhsh[1], Seyyed Ali Mohammad Taghavi[2], Hamid Jalilvand[3], Farzaneh Fatahi[1]

[1] *Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*
[2] *Department of Accounting, Dehdasht Branch, Islamic Azad University, Dehdasht, Iran*
[3] *Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

Use your device to scan and read the article online

Citation: Taghavi SMR, Mohammadkhani G, Rouhbakhsh N, Taghavi SAM, Jalilvand H, Fatahi F. Determining Frequency Importance Function for Speech Intelligibility of Persian Monosyllabic Words and the List of Quick Speech in Noise in Persian Language. Aud Vestib Res. 2023;32(4):261-71.

https://doi.org/10.18502/avr.v32i4.13590

Highlights

- An important part of SII for a specific language is the frequency importance function
- The FIF represents the relative importance of each speech frequency band
- The frequency importance function varies between different languages

Article info:
Received: 12 Mar 2023
Revised: 16 Apr 2023
Accepted: 25 Apr 2023

[*] **Corresponding Author:**
Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran.
mohamadkhani@tums.ac.ir

ABSTRACT

Background and Aim: The Frequency Importance Function (FIF) is the main component of the Speech Intelligibility Index (SII) for a certain language. The FIF indicates the relative importance of each frequency band as it contributes to speech intelligibility. This study was conducted to determine the FIF for the Persian monosyllabic words and the list of Quick Speech in Noise (QSIN) in Persian language.

Methods: In this exploration study, 34 monolingual Persian-speaking subjects aged 25–40 years with normal hearing (17 males) were included. The FIF was evaluated for 100 monosyllabic words and 30 sentences of Persian QSIN under 180 different auditory conditions. The speech recognition scores were calculated and crossover frequencies were determined. Then, the relative transfer function was extracted and FIFs were calculated.

Results: The findings showed that for monosyllabic word material, the FIF had three peaks at 178, 1787, and 4467 Hz and for Persian QSIN, the FIF had an initial peak at about 141 Hz followed by a peak at about 1800 Hz. According to the results, the frequency range 891–8913 Hz is very important for recognition of the Persian words. Moreover, the mean crossover frequencies for the Persian sentences was 1446 Hz.

Conclusion: For monosyllabic word material in the Persian language, the FIF at 708–1778 Hz is very important for recognition of the Persian monosyllabic words. For sentence material in the Persian Language, the FIF at 708–4467 Hz has the highest importance for recognition of Persian sentences.

Keywords: Frequency importance function; speech intelligibility index; monosyllabic word; quick speech in noise list; Persian language

Introduction

The Articulation Index (AI) is an important tool for prediction of speech intelligibility and has gained an increasing importance for evaluation of hearing aids fitting [1, 2]. In recent years, AI has been used to assess standard clinical speech tests and to evaluate the performance of hearing aids [3]. The term AI was first introduced as an acoustic index by the American National Standard Institute (ANSI) in 1969 to predict the speech recognition capability of adults with normal hearing in different speech conditions like using the phone or radio communication between pilots. AI was not used in subjects with hearing impairment until the early 1980s [4-7]. The term AI was later changed to the Speech Intelligibility Index (SII). SII is a quantitative parameter that shows the contribution of audible speech cues in the specific frequency bands to speech recognition [8]. It is a useful tool for estimating the speech recognition ability in special listening condition [9, 10]. To determine the SII, it is necessary to have a comprehensive understanding of the frequency importance function of a specific speech material since different frequency bands do not have a similar relative importance. An important part of SII for a specific language is the Frequency Importance Function (FIF) for that language. The FIF represents the relative importance of each speech frequency band as it contributes to speech intelligibility. Considering that different languages have differences, it is accepted that certain frequency bands may be more important to intelligibility in one language over another. The method of obtaining FIF involves collecting speech recognition scores while participants listen to Low-Pass (LP) and High-Pass (HP) filtered speech, at different frequency cut-off regions and Signal-to-Noise Ratio (SNR). Initially speech recognition scores for LP and HP filtered speech bands are plotted as a function of cut-off frequencies to produce cross-over frequencies, or the point at which LP and HP filtering yields equivalent performance. According to the ANSI S3.5 (1997) standard, SII is calculated using the following mathematical equation [11].

$$1)\quad SII=\sum_{i=1}^{n} I_i A_i$$

Where I_i shows the relative importance of the i frequency band in the speech spectrum and is related to the degree to which this speech frequency band contributes to speech intelligibility. In fact, it indicates the FIF for that language. A_i is a function showing the amount of speech energy available in each frequency band that contributes to the overall recognition. In fact, the FIF of a given language is the key component of SII for that language [11]. The FIF represents the relative importance of each frequency band as it contributes to speech intelligibility. It has been confirmed that the FIF differs across languages [12-14]. So far, the FIF has not been investigated in the Persian language, and on the other hand, we know that optimal speech understanding for Persian-speaking people with hearing loss can only be achieved by determining the FIF for the Persian language. Audiologists know that hearing aid prescription formulas should provide appropriate amplification for those frequency areas that play a fundamental and important role in speech understanding, but so far this has not been achieved because the FIF was not available for the Persian language. The present study was conducted to determine the FIF for speech intelligibility of Persian monosyllabic words and the list of Persian Quick Speech in Noise (QSIN).

Methods

Participants

Thirty-four subjects (17 males) with normal hearing participated in the present study. The age range of the subjects was 25–45 years (28.12±0.12 years). The participants were selected from the students of Tehran University of Medical Sciences. All people's first language was Farsi. All subjects had a normal tympanometry and normal hearing with a hearing threshold<15 dB at 250–8000 Hz (5.45±1.17 dB). None of the participants reported a history of middle ear disease or head trauma nor were they professional musicians. All of them were monolingual Persian native speakers.

Speech material

The speech material was a list of monosyllabic words prepared by Mosleh [15] and the list of QSIN sentences developed by Moossavi et al. [16]. Four lists each containing 25 words (a total of 100 words) with the highest phonetical balance and five lists each containing 6 sentences (30 sentences in total) were used in the study. The lists were presented to expert broadcasters to read the words and sentences. During recording, the broadcasters were asked to read the words and sentences clearly and naturally. To create a similar speech quality in terms of pronunciation, the speech rate was about 4 syllables per second.

Equipment

The test material was recorded in an acoustic environment to provide the highest quality. The equipment used for recording included a dynamic microphone headset with a high sensitivity (Neumann TLM 102) connected to a sound card (Focusrite Saffire Pro 40) using a connector that could record/playback at 24-bit/96 kHz. The input was recorded directly to the Cubase software installed on a laptop Lenovo Ideapad 5. A sampling frequency of 44.1 kHz with 16-bit amplitude resolution was used for recording. During the recording session, the broadcaster wore the headset microphone at a fixed distance of 13 mm and the angle of the headset microphone with the mouth of the broadcaster was 0 degree. The broadcaster was instructed to speak at a normal loudness level corresponding to about 65 dB SPL as monitored by the A weighting Larson Davis System 824 sound level meter. In the next step, the recorded speech was edited from the waveform into monosyllabic word units and sentence units. The silent period at the beginning and end of each speech unit was always less than 1 ms to eliminate intensity differences that might have arisen if too much silence was attached to the tokens when noise was added to the speech signals. In total, 100 monosyllabic words and 30 sentences were prepared. According (ANSI S3.5-1997) Standard [11] the average root mean square (rms) of these units at a tone of 1000 Hz was used for intensity normalization. First, the average RMS of each word and sentence was measured [11]. Then, the noise files were generated by shaping the white noise to match the average spectrum of each word and sentence file using the MATLAB software. Therefore, a similar noise file was created for each monosyllabic word and sentence.

Preparation of word material

The MATLAB software was used to filter audio files and mix filtered speech with noise. In the software, each speech file was placed in channel 1 and the noise file was placed in channel 2. The word or sentence in channel 1 were filtered using high-pass and low-pass filters (141, 224, 355, 562, 891, 1413, 2239, 3548, 5623, and 8913 Hz). To filter the speech using low-pass and high-pass filter, the speech signal was passed through a broadband digital filter (110–11000 Hz) using the hamming windowing function with a sharp cut-off of 60 dB/octave to ensure as little overlap as possible between frequency bands [1]. Moreover, the intensity of the filtered speech was reinforced or attenuated according to the noise level on channel 2 (signal to noise ratios of –9, –6, –3, 0, 3, 6, 9, 12, and 15 dB). Finally, the speech and noise channels were mixed to create a single waveform in channel 1 and 2. After preparing the words and sentences as described above, auditory evaluation was conducted.

Auditory evaluation

For auditory evaluation before speech test, otoscopic examination was done to ensure lack of impacted cerumen or tympanic inflammation. Then, tympanometry was done to evaluate the middle ear function. Pure-tone audiometry was done to determine the auditory threshold. Since the test was conducted in two sessions one week apart to prevent exhaustion, tympanometry and acoustic reflex were performed at the beginning of each session. Moreover, the participants were asked if they were exposed to loud noise and noticed any change in auditory sensitivity compared to the previous session. If there was a change in the hearing of the study participants in the interval between the sessions, the person was excluded from the study, Also, if the person did not want to continue cooperating in the study, he/she could withdraw from the study. None of the participants in the study had any problems during the interval between the sessions and were not excluded from the study.

Test guideline

Persian monosyllabic words and QSIN sentences were recorded in an acoustic chamber to minimize the background noise. The participants were instructed by researcher to repeat the speech materials they heard so that the researcher could record them. The word recognition score was calculated and the percentage of the correct answers was recorded as the speech recognition score. The participants were allowed to take a break whenever they felt exhausted.

FIFs are calculated in several steps [17-19]. First, the speech recognition score was calculated as percentage and placed in tables representing functions of different LP and HP cut off frequencies at different SNRs. Then, crossover frequencies were determined using curves derived from the tables. Crossover frequencies are the intersection points of plotted speech recognition scores for HP and LP filtered frequency bands at each SNR. In the next step, using the data smoothing method, the curves were smoothed to ensure that the performance decreased constantly with speech matrial become lessaudible [20].

The Relative Transfer Function (RTF) was derived through fitting relative data between SII values and speech recognition scores using the curve bisection method. To calculate this function, the maximum SII value is considered 1.0, which equals the highest speech recognition score (100%) in unfiltered conditions. The curve bisection method is used to determine other value of the SII, and the smoothed data for the HP and LP filters for the highest SNR are plotted as a function of the cut off frequency [18, 19-21]. In this method, 100% speech recognition indicates a SII value of 1.0, 0% speech recognition indicates a SII value of 0.0, and 50% speech recognition indicates a SII value of 0.5. This bisection method was continued until other reference points (i.e. SII values of 0.25, 0.125, etc.) were also determined. Therefore, the importance of each frequency band was calculated using RTF to convert the SII value of each frequency band to a relative percentage scale [21]. Curve fitting software was used to take fitting constants Q and N [21]. Both Q and N are fitting constants and depend on the characteristics of the speech materials [18]. More specifically, Q is a correction factor to compensate for changes in proficiency with the test materials under experimental conditions; and N represents the number of independent sounds in a test item or a constant that controls the shape of the function curve. To obtain the fitting constants Q and N [11], the scores and the corresponding SII obtained were substituted into both equations in order to recognize the best fit curve (maximum r2) for Q and N using MATLAB.

Results

After conducting speech tests in different conditions, obtaining speech recognition scores, and plotting these scores as a function of HP and LP cut-off frequency at different SNRs, crossover frequencies were obtained (Table 1). High-pass and low-pass plot did not intersect each other at any points at a SNR of –9 dB. The Cross-over Frequency (CF) was calculated using the geometric mean of the intersect frequencies of all SNRs using smoothed data, and the geometric mean of Cross-Over

Table 1. Crossover frequencies at different signal to noise ratios for monosyllabic words and quick speech in noise sentences in the Persian language

Signal to noise ratio	Sentence (Hz)	Word (Hz)
+15	1193	1923
+12	1285	1714
+9	1319	1539
+6	1363	1774
+3	1063	1743
0	1952	1850
–3	1952	1978
–6	7270	4221
–9	-	-
Mean	1446.71	1788.71
SD	358.63	145.89

frequency for was words calculated 1788 Hz and 1446 Hz for sentences.

Relative transfer function

The Relative Transfer Function (RTF) was derived through fitting relative data between SII values and speech recognition scores using the curve bisection method. For example, at the SNR of 15 dB, the maximum speech recognition occurs in the cutoff frequency range below 5623 Hz and above 224 Hz for words (Figure 1).

Therefore, the CF below 5623 Hz and above 224 Hz offers the maximum recognition. The SII value for 1923 Hz CF is 0.5 because half of the total auditory area is available to the listener above or below this point, and it is assumed the total area for the SNR +15 dB has a SII of 1.00. Using the SII value of 0.5, other points can be calculated. According to the method used in previous studies, 13 sets of SII values were calculated using the speech recognition scores [21].

In the next step, the MATLAB software was used to fit the SII values and speech recognition scores using the following equations:

2) $$s = \left(1 - 10^{-PA/Q}\right)^{N}$$

3) $$A = -\frac{Q}{P}\log\left(1 - S^{\frac{1}{N}}\right)$$

Equation 1 was used to predict the speech recognition score percentage according to the SII and Equation 2 was applied to predict the SII value according to the speech recognition score. In these equations:

S: speech recognition score

P: factors affecting the function of listeners. Since the broadcaster and listener were Persian native speakers, a value of 1 was considered for this factor.

A: speech intelligibility index

To identify the Q and N constants, the speech recognition scored and SII values were used in the

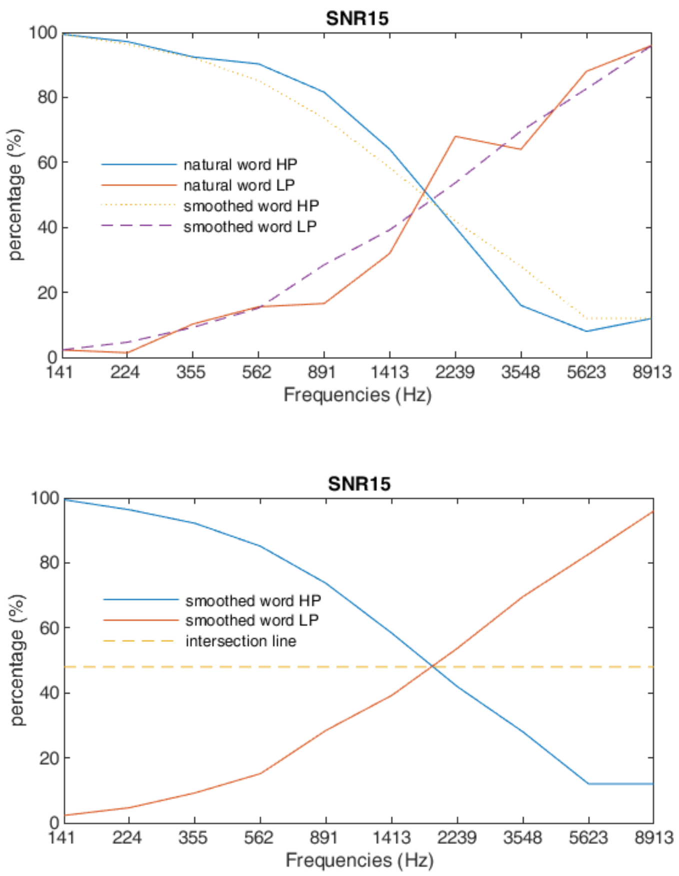

Figure 1. Upper image shows the plot of speech recognition scores in high-pass filter (blue line) and low-pass filter (red line) according to cut off frequencies at the SNR of 15 dB for Persian monosyllabic words. Solid red and blue lines indicate unsmoothed data and yellow and purple dotted lines show smoothed data. Lower image demonstrates smoothed plot where a yellow dotted line crosses the intersection of the solid red and blue lines. This point represents the crossover frequency indicating a SII value of 0.5. SNR: signal to noise ratio

equations to obtain the best fit curve (maximum R^2) for Q and R. Table 2 presents Q, N, and R^2 values [21]. The RTF for word material and sentence was estimated the SII value. Figure 2 shows relative transfer function for Persian monosyllabic words and QSIN sentences.

Frequency importance functions

RTF was used to calculate FIF according to previous studies [17, 18]:

1) The mean HP and LP recognition scores for each SNR were converted to SII values by using equation 3 and inserting the recognition scores and the fitting constants Q and N and converting to SII.

$$4)\quad A=-\frac{Q}{P}\log\left(1-S^{\frac{1}{N}}\right)$$

This equation was calculated for all CFs at different SNRs. Then, the SII value was calculated for each frequency band. For the LP data, this was applied by subtracting the SII value of the lower CF from the SII value for the higher CF. A reverse method was used for HP data, i.e. the SII value for 891 Hz cut-off frequency was subtracted from the SII value for 562 Hz cut-off frequency. Therefore, two estimates, one LP estimate and one HP estimate, were obtained for the SII for each band at each SNR. Then, the LP and HP estimates were averaged to obtain a single estimate for each frequency band and SNR. The data were then used to calculate frequency importance values. The importance percentage or FIF is the SII value converted to percentage, which is calculated by dividing each mean SII value by the sum of mean values multiplied by 100 Tables 3 and 4). The summary of importance each frequency band values converted to percentage for word and sentence material are presented in the Table 5. Then Relative Transfer Function plot for Persian monosyllabic words and quick speech in noise sentences in Persian language was obtained (Figure 3).

Discussion

The present study was conducted to evaluate the FIF for Persian monosyllabic words and the QSIN sentences in Persian language. The FIF for monosyllabic words

Table 2. Q, N, and R2 values for equation 1 and 2

Speech martial	SII value estimate			Speech recognition score percentage estimate		
	R^2	N	Q	R^2	N	Q
Word	0.94	6.10	0.38	0.97	3.26	0.58
Sentence	0.96	5.41	0.39	0.99	4.76	0.45

SII; speech intelligibility index

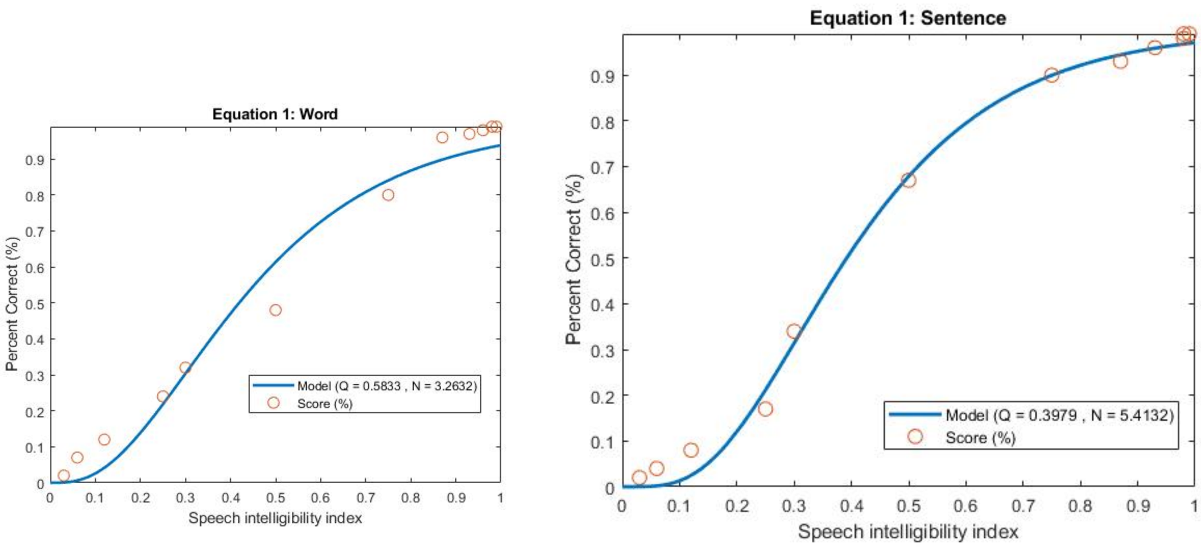

Figure 2. Relative transfer function for Persian monosyllabic words and quick speech in noise sentences in Persian language

and sentences in Persian and other languages is compared in the following.

Other studies conducted in this regard include three studies that used W-22 [20], NU-6 [1], and PB-50 [22] word tests, which are presented in Figure 4. And two Mandarin studies using 50 phonetically balanced words [12, 13].

Word frequency importance functions

In the present study, the FIF had a peak at around 178 Hz. The three English monosyllabic word FIFs have no peak in the 178 Hz. also the two Mandarin monosyllabic word FIFs reported by Cheng et al. [23] and Chen et al. [13] are different from the FIFs derived in this study and there are no peaks in the 178 Hz. The second peak for

Table 3. Data related to Speech intelligibility index values for Persian monosyllabic words

Importance (%)	Mean	Signal to noise ratio									Band (Hz)	Center (Hz)
		−9	−6	−3	0	3	6	9	12	15		
24.24	0.08	0.00	0.01	0.41	0.02	−0.00	0.02	0.07	0.05	0.12	141-224	178
2.85	0.00	0.05	0.06	−0.40	0.06	−0.00	0.02	0.04	0.11	0.12	224-355	282
3.54	0.01	−0.04	−0.03	0.04	−0.00	0.03	0.00	0.02	0.04	0.03	355-562	447
10.97	0.03	0.00	0.00	0.02	0.02	0.04	0.05	0.08	0.03	0.05	562-891	708
10.10	0.03	0.04	−0.09	0.05	0.05	0.02	0.01	0.02	0.08	0.09	891-1413	1122
17.88	0.05	0.00	0.06	0.01	0.02	0.04	0.07	0.04	0.13	0.14	1413-2239	1778
5.79	0.01	−0.06	−0.07	0.01	0.00	0.04	0.07	0.08	0.04	0.03	2239-3548	2818
14.91	0.04	0.00	0.02	0.08	0.01	0.05	0.05	0.09	0.07	0.13	3548-5623	4467
9.72	0.03	0.00	0.00	0.01	0.00	0.05	0.03	0.00	0.09	0.08	5623-8913	7080
100	0.33						**Total**					

Table 4. Data related to speech intelligibility index values for quick speech in noise sentences in Persian language

Importance (%)	Mean	Signal to noise ratio						Band (Hz)	Center (Hz)
		−9	−6	−3	0	+3	+6		
13.43	0.06	−0.03	0.01	0.06	0.00	0.02	0.0	141-224	178
5.51	0.02	0.00	0.00	0.01	0.02	0.04	0.07	224-355	282
10.21	0.04	0.03	0.03	0.01	0.02	0.09	0.08	355-562	447
9.53	0.04	−0.00	0.02	−0.00	0.02	0.11	0.12	562-891	708
10.48	0.05	0.00	0.00	0.06	0.16	−0.00	0.07	891-1413	1122
14.20	0.06	−0.05	0.05	0.01	0.04	0.18	0.18	1413-2239	1778
9.53	0.04	0.00	0.00	0.00	0.00	0.10	0.15	2239-3548	2818
22.02	0.10	−0.01	−0.04	−0.01	0.11	0.06	0.52	3548-5623	4467
5.09	0.02	−0.00	0.05	0.00	0.04	0.03	0.01	5623-8913	7080
100	0.48					Total			

Table 5. Summary of importance of each band in recognition for Persian monosyllabic words and quick speech in noise sentences in Persian language

Sentence (%)	Word (%)	Frequency band (Hz)	CF (Hz)
13.43	24.24	141-224	178
5.51	2.85	224-355	282
10.21	3.54	355-562	447
9.53	10.97	562-891	708
10.48	10.10	891-1413	1122
14.20	17.88	1413-2239	1778
9.53	5.79	2239-3548	2818
22.02	14.91	3548-5623	4467
5.09	9.72	5623-8913	7080

CF; center frequency

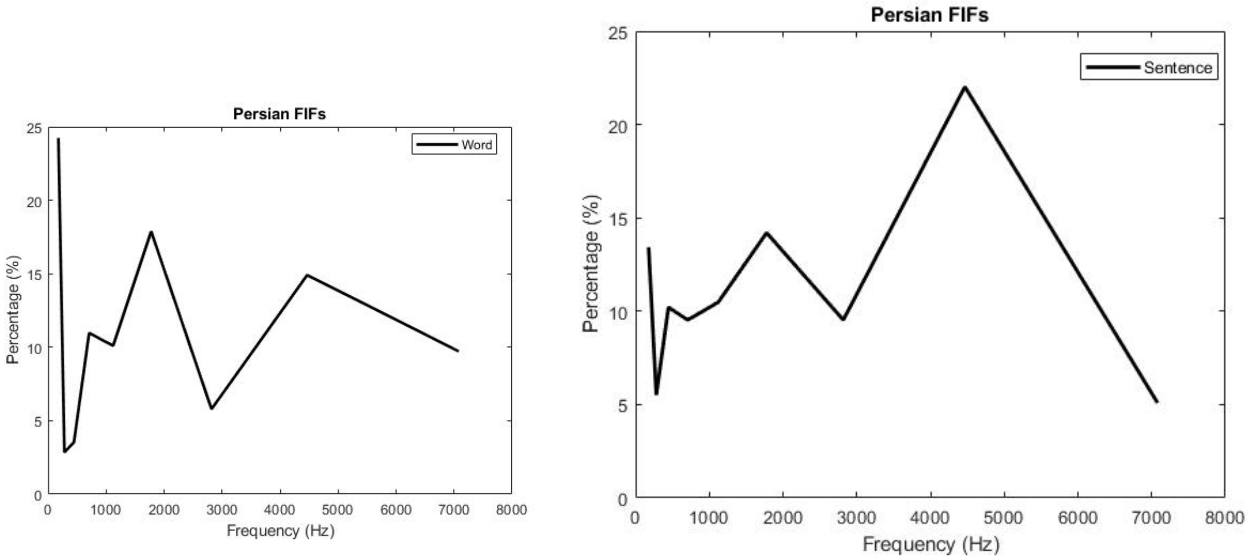

Figure 3. Relative transfer function plot for Persian monosyllabic words and quick speech in noise sentences in Persian language. FIF; frequency importance function

Persian words was observed at around 1787 Hz, which was similar to the above English studies with a peak at 1800 Hz. In two studies, the FIFs of monosyllabic words was investigated in Mandarin language the frequency of 2500 was more important.

Although there is a stable pattern whereby these English word FIFs peak at ~1800 Hz and have greater importance than current Persian in the range of 891–8913Hz, there is also significant variation between the percentage importance weighting centered on 1800 Hz for the English studies. This variability can be due to the use of different filtering bands, different numbers of conditions, different word lists, and/or different methods of smoothing the data. For instance, Depaolis et al. [21] used only 9 filtering conditions using the PB-50 test compared Studebaker's et al [1] use of 20 filtering conditions using the NU-6 test and the W-22 test [21]. In addition, there is no consensus on a procedure that should be followed to smooth speech recognition data. The SRT data smoothing method involved in FIF derivation in the present study with English were smoothed by eye using independent judgments.

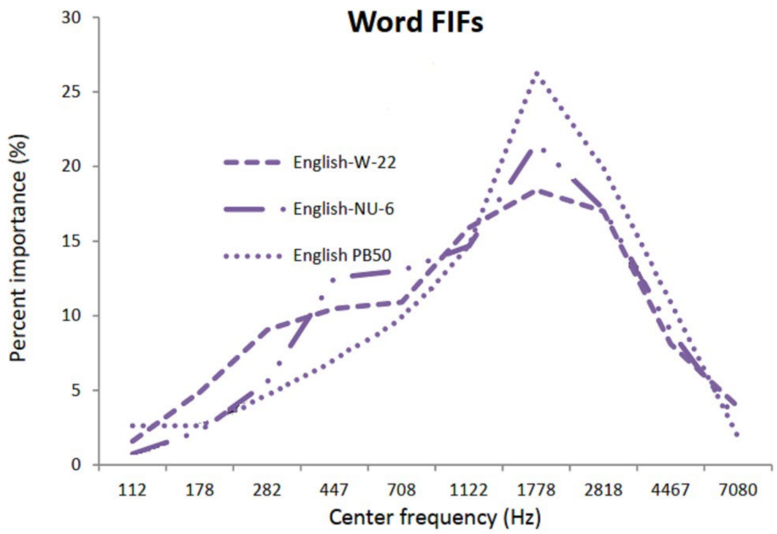

Figure 4. Frequency importance function plot for English words. FIF; frequency importance function

About mandarin study There are methodological differences. Firstly, there were only two participants in the Cheng et al. study [23] and no mention of participant numbers in the Chen et al. study [13]. Secondly, both these studies used 50 monosyllabic words for total of 320 test conditions, compared to 100 words for total of 180 conditions in the current study. Using 50 words for 320 conditions would mean that all words are repeated at least four times, and this could lead to a familiarity or learning effects. When learning is involved in a speech recognition test it may affect speech recognition scores.

According to the results, the frequency range 891–8913 Hz is very important for recognition of Persian words, which is also true for English words. However, it can be argued that this range has a higher importance (about 10%) for recognition of English monosyllabic words compared to Persian monosyllabic words.

This difference can be due to the number of bands used in different studies. Furthermore, it seems that higher frequencies play a more important role in the intelligibility of the English language compared to Persian.

Sentences frequency importance functions

For sentence martials Other studies in this regard include a study by DePaolis et al. [21] that used the English version of the SPIN test and in another study [12] that used the Cantonese version of the HINT test (Figure 5).

The first peak formed in the present study and the study by Wong et al was obtained at 141 Hz, which was not found in the study conducted by DePaolis et al [21]. Indicating that Persian and tonal language listeners need more weighting at lower frequencies for differentiating some speech data compared to the English language.

The next peak for sentences was at 1800 Hz, which was also observed for the English and Cantonese versions; however, the shape of the frequency importance function for Persian sentences and English languages had a narrower amplitude compared to the Cantonese language, which may be related to the differences in the phoneme supply between Persian, English, and Cantonese languages.

Another point is related to crossover frequencies that were calculated for HP and LP frequency bands at different SNRs. The mean crossover frequency was 1446 for Persian sentences, which it was 1599 Hz for the English version of the SPIN test [21] and much lower, i.e., about 1075 Hz, in the Cantonese version of the HINT test [12]. Therefore, it can be concluded that sentences in the Cantonese language contain more speech information in low frequency areas compared to English and Persian languages.

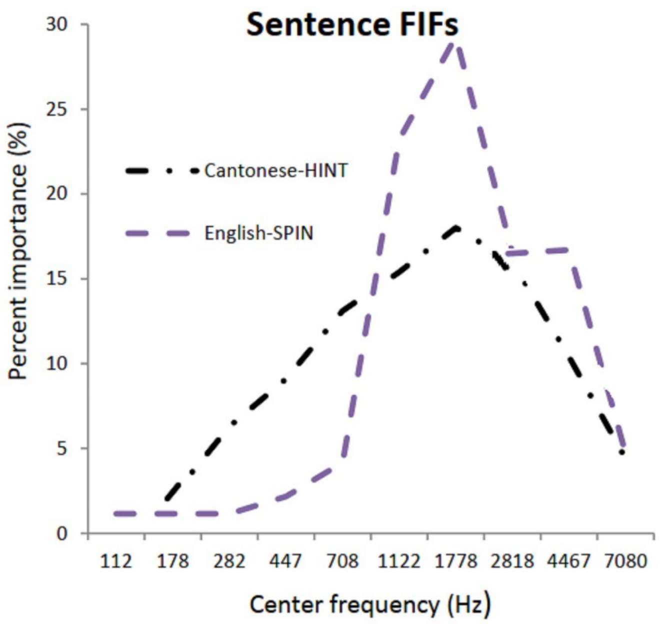

Figure 5. Frequency importance function for speech-in-noise in English language and the hearing in noise test in Cantonese language. FIF; frequency importance function, SPIN; speech-in-noise test, HINT; hearing in noise test

Since no similar study has been conducted in Persian language, it is not possible to compare the results of the present study with other studies.

Since no similar studies have been conducted in Persian language, it was not possible to compare the results with other studies in Persian language. The FIFs obtained in this study have several important implications regarding the way hearing aids are adjusted for Persian speakers. Although this study is the first step in the development of hearing aid adjustment formula for Persian language. Current research on Persian FIFs is far from adequate in providing speech intelligibility values for clinical hearing evaluations in order to make appropriate language-specific adjustments to hearing aids. To change and modify the current version of the hearing aid setting which is based on English for Persian users, more research should be done. In the next step, the aim is to use the results of the present study and adapt them to everyday conditions in order to investigate different speakers.

Conclusion

The frequency importance function (FIF) for Persian monosyllabic words has several peaks at 178, 1787, and 4467 Hz. The results indicated that the frequency range 708–1778 Hz is very important for recognition of Persian monosyllabic words and according to the present study, the mean crossover frequency for Persian sentences was 1446 Hz. Moreover, the importance frequency function for Persian sentences had two peaks at 141 and 1800 Hz. Expanding of FIFs like this, not only provides an understanding of the frequency band weightings that affects Persian monosyllabic words, but in addition provides performance intensity functions to aid understanding of how speech recognition changes as a function of signal-to-noise ratio; and finally, it provides a series of cross-over frequency s and relative transfer function that enable prediction of speech intelligibility index values for people in everyday communication.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by ethic committee of Tehran university of medical science (Code: IR.TUMS.FNM.REC.1400.156).

Funding

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

Authors' contributions

SMRT: Study design, acquisition of data, interpretation of the results, statistical analysis, and drafting the manuscript; GM: Study design, drafting the manuscript, supervising the manuscript; NR: Study design, drafting the manuscript; SAMT: Statistical analysis; HJ: Study design, drafting the manuscript; FF: Drafting the manuscript.

Conflict of interest

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

Acknowledgements

This research has been supported by Tehran University of Medical Sciences grant number 1401-2-103-55654.

References

[1] Studebaker GA, Sherbecoe RL, Gilmore C. Frequency-importance and transfer functions for the Auditec of St. Louis recordings of the NU-6 word test. J Speech Hear Res. 1993;36(4):799-807. [DOI:10.1044/jshr.3604.799]

[2] Hou Z, Thornton AR. A model to evaluate and maximize hearing aid performance by integrating the articulation index across listening conditions. Ear Hear. 1994;15(1):105-12. [DOI:10.1097/00003446-199402000-00013]

[3] Pavlovic CV. Band importance functions for audiological applications. Ear Hear. 1994;15(1):100-4. [DOI:10.1097/00003446-199402000-00012]

[4] French NR, Steinberg JC. Factors Governing the Intelligibility of Speech Sounds. J Acoust Soc Am. 1947;19(1):90-119. [DOI:10.1121/1.1916407]

[5] Braida LD, Dugal RL, Durlach NI. Choosing the frequency responses of hearing aids—the viewpoint of a communications engineer. J Acoust Soc Am. 1979;66(S1):S16-7. [DOI:10.1121/1.2017636]

[6] Kamm CA, Dirks DD, Bell TS. Speech recognition and the Articulation Index for normal and hearing-impaired listeners. J Acoust Soc Am. 1985;77(1):281-8. [DOI:10.1121/1.392269]

[7] Pavlovic CV. Use of the articulation index for assessing residual auditory function in listeners with sensorineural hearing impairment. J Acoust Soc Am. 1984;75(4):1253-8. [DOI:10.1121/1.390731]

[8] Amlani AM, Punch JL, Ching TY. Methods and applications of the audibility index in hearing aid selection and fitting. Trends Amplif. 2002;6(3):81-129. [DOI:10.1177/108471380200600302]

[9] Hornsby BW. The Speech Intelligibility Index: What is it and what's it good for?. Hear J. 2004;57(10):10-7.

[10] Halpin C, Thornton A, Hous Z. The articulation index in clinical diagnosis and hearing aid fitting. Curr Opin Otolaryngol Head Neck Surg. 1996;4(5):325-34.

[11] Pavlovic C. SII—Speech intelligibility index standard: ANSI S3.5 1997. J Acoust Soc Am. 2018;143(3):1906. [DOI:10.1121/1.5036206]

[12] Wong LL, Ho AH, Chua EW, Soli SD. Development of the Cantonese speech intelligibility index. J Acoust Soc Am. 2007;121(4):2350-61. [DOI:10.1121/1.2431338]

[13] Chen J, Qu TS, Wu XH, Huang Q, Huang Y, Li L, et al. Frequency importance function of Mandarin Chinese speech. J Acoust Soc Am. 2008;123(5):3323. [DOI:10.1121/1.2933807]

[14] Taghavi SMR, Mohammadkhani G, Jalilvand H. Speech Intelligibility Index: A Literature Review. Aud Vestib Res. 2022;31(3):148-57. [DOI:10.18502/avr.v31i3.9861]

[15] Mosleh M. [Development and Evaluation of a Speech Recognition Test for Persian Speaking Adults]. Audiol. 2001;9(1-2):72-6. Persian.

[16] Moossavi A, Javanbakht M, Arbab Sarjoo H, Bakhshi E, Mahmoodi Bakhtiari B, Lotfi Y. Development and Psychometric Evaluation of Persian version of the Quick Speech in Noise Test in Persian Speaking 18-25 Years Old Normal Adults. JRSR. 2016;3(3):51-6. [DOI:10.30476/jrsr.2016.41099]

[17] Duggirala V, Studebaker GA, Pavlovic CV, Sherbecoe RL. Frequency importance functions for a feature recognition test material. J Acoust Soc Am. 1988;83(6):2372-82. [DOI:10.1121/1.396316]

[18] Studebaker GA, Pavlovic CV, Sherbecoe RL. A frequency importance function for continuous discourse. J Acoust Soc Am. 1987;81(4):1130-8. [DOI:10.1121/1.394633]

[19] Bell TS, Dirks DD, Trine TD. Frequency-importance functions for words in high- and low-context sentences. J Speech Hear Res. 1992;35(4):950-9. [DOI:10.1044/jshr.3504.950]

[20] Studebaker GA, Sherbecoe RL. Frequency-importance and transfer functions for recorded CID W-22 word lists. J Speech Hear Res. 1991;34(2):427-38. [DOI:10.1044/jshr.3402.427]

[21] DePaolis RA, Janota CP, Frank T. Frequency importance functions for words, sentences, and continuous discourse. J Speech Hear Res. 1996;39(4):714-23. [DOI:10.1044/jshr.3904.714]

[22] American National Standards Institute. "Methods for calculation of the speech intelligibility index."(ANSI, S3 22-1997). New York: 1997.

[23] Cheng YY, Wu HC, Tzeng YL, Yang MT, Zhao LL, Lee CY. The development of mismatch responses to Mandarin lexical tones in early infancy. Dev Neuropsychol. 2013;38(5):281-300. [DOI:10.1080/87565641.2013.799672]