Research Article

Development of a Binaural Masking Level Differences Test Application Using Tonal and Speech Stimuli in Persian and Assessing Its Test-Retest Reliability in Normal-Hearing Young People

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Highlights

- A BMLD test application was designed using tonal and speech stimuli in Persian
- Release from masking plays a significant role in speech perception in noise

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ABSTRACT

Background and Aim: The masking level difference (MLD) test is a behavioral test that assesses binaural interactions and central auditory processing. This study aims to design a binaural MLD (BMLD) test application using tonal and Speech Stimuli in Persian.

Methods: In the first stage, the BMLD test application was designed in MATLAB software. Then, the spondaic words were recorded and added to the sound processing panel of the application. In the next stage, the MLD of tonal and speech stimuli was measured on 20 subjects aged 18–25 years. To examine the test-retest reliability of the application, all steps were repeated after one week.

Results: The MLD values for tonal and speech stimuli under the SoNo-SπNo condition were significantly different from those under the SoNo-SoNπ condition ($p<0.05$). These values for tonal and speech stimuli were 10.50 and 6.12 dB under the SoNo- SπNo condition, and 6.85 and 4.43 under the SoNo- SoNπ condition. There was no significant difference in the MLD values between males and females. The intraclass correlation coefficient value for different phase conditions was more than 0.8, indicating the high reliability of the BMLD test application for tonal and speech stimuli in Persian ($p<0.05$).

Conclusion: The designed BMLD test application using tonal and speech stimuli in Persian has similar results compared to the conventional methods of MLD test for other languages, therefore, this application can be used in audiology clinics in Iran to perform the MLD test.

Keywords: Release from masking; masking; binaural hearing; software

Introduction

The use of both ears to hear the ambient sound is defined as binaural hearing. Binaural hearing has benefits compared to when only one ear is used. Binaural hearing enhances auditory sensitivity; i.e. causes more exact auditory signals localization and speech perception in noise whenever the sources of signal and noise are segregated [1-4]. Spatial hearing is one of the most important agents that empowers humans in communication skills. It provides information about the location, number of sound sources, and objects in the environment and helps determine the characteristics and dimensions of enclosed spaces and the cocktail party effect when the listeners are able to hear the voices in the presence of noise [1].

A sound stimulus is composed of intensity, frequency, and time elements. Therefore, two sounds with equal frequency and intensity, originating directly in front or back of a person with normal hearing, which arrives at the ears simultaneously and may not be distinguished from each other. A small change in any of these features is recognized by the auditory system, which responds to it to be analyzed in binaural hearing. The change can be interaural time difference (ITD), interaural loudness difference, interaural frequency difference, and head-related transfer function. These changes are analyzed by higher and lower auditory processing systems [5, 6]. The binaural interaction starts in the subcortical area of the central auditory nervous system (CANS), more specifically in the superior olivary complex and a region near the nucleus of the inferior colliculus and the lateral lemniscal [7, 8]. The auditory cortex may also be involved, directing information processed in the auditory pathway to proper perceptual and motor spatial processing areas [9].

Hearing skills refer to the auditory system and are bottom-up factors related to the acoustic signals representation. However, the act of auditory does not merely imply detection of an acoustic stimulus, since hearing skills depend on multiple cognitive and neurophysiological mechanisms. Moreover, top-down processes are necessary; even the simplest hearing event is affected by higher-level cognitive factors such as learning, attention, and memory [10-13]. Binaural interaction is related to selective attention, but some studies suggest that cognitive skills and attention have little impact on this mechanism [1]. Auditory complaints about difficulties locating the sound source and understanding speech in noisy environments may be associated with impairment of binaural interaction functions [14]. The psychoacoustic phenomenon is defined as release from masking which shows increased recognition or detection of a signal presented in mono or binaural conditions in a noisy environment. This phenomenon is due to the auditory system's use of a delicate binaural event and the differences in amplitude levels between signals presented at the same time or masked signals [15-22].

The binaural interaction can be evaluated mainly by two behavioral methods: the binaural fusion test and the masking level difference (MLD) test. The MLD phenomenon was described for the first time by Hirsh for pure tones [16] and by Licklider for speech signals [15]. The MLD test is one of the most reliable behavioral tests for the assessment of brainstem function. The MLD test can be done by an audiometer or a compact disc (CD) recording of the version developed by Wilson et al, commercially available from Auditec of Saint Louis®. It includes the presentation of 33 segments of narrow-band noise (NBN) in both ears for at least three seconds in the absence or presence of a 500 Hz signal [22]. Three different conditions are used: pure tone and NBN in phase in both ears (homophasic signal/noise condition, SoNo); out-of-phase pure tone in one ear and homophasic noise in both ears (signal/noise condition, SπNo) or vice versa (SoNπ) [18]. The task is to show whether the tone has been heard or not by raising the hand when it is heard. The final result is the difference in dB between the scores under SoNo and SπNo or SoNo and SoNπ conditions. In normal brainstem function, the MLD value under the antiphasic condition is more than in the homophasic condition. This enhancement is indicative of the release from masking phenomenon, which emerges from the CANS, where the integration of information coming from both ears occurs first [14, 17]. The MLD value for pure tones at low frequencies is about 15 dB around 500 Hz and decrease to approximately 3 dB at frequencies above 1500 Hz. The level of correlation between the noise in the right and the left ears affects the MLD value, which increases at higher levels of correlation [17]. The stimulation duration does not affect the MLD value. Although the masked threshold decreases with increased stimulation duration, the MLD value remains constant. Therefore, the MLD would be detectable at both short and long durations of presenting speech stimuli. Wilson et al. showed a difference of about 3-4 dB in the MLD value for spondaic words when using 2000-ms bursts of broadband noise (BBN), instead of a continuous BBN, as a masker [22].

The detection of monosyllabic words in noise is influenced similar to low-frequency pure tones, with an MLD value of about 13 dB at frequencies below 500 Hz. The effect of phase change on speech recognition is less than on speech detection. At a recognition level of 50%, the binaural intelligibility level difference (BILD), i.e. the difference in MLD values between two binaural conditions, is about 6 dB. At the higher signal-to-noise ratios, with higher intelligibility, the effect of ITD and BILD at low frequency decreases [18, 22]. Wilson et al. reported binaural masking level differences (BMLDs) of 9.4 and 7.2 dB for speech detection and speech recognition, respectively, using spondaic words. Other studies have reported similar effects for spondaic words [22].

The MLD test can provide information about binaural interaction in terms of temporal and spatial processing ability and can show dysfunction below the cortex in the brainstem area of the central nervous system. MLDs are an important component of test batteries for auditory processing dysfunction (APD) [21]. Obviously, tonal MLDs prepare a useful tool in differentiating between normal and non-normal patients. MLDs that are significantly lower than normal are a symptom of APD and illustrate further APD testing [17]. Since most studies on MLD have been conducted using pure tone detection tests, this study will focus on speech perception in noise and the benefit of phase change for speech recognition. Wilson et al. and others have used spondaic words in English [6, 18, 22], but no results using Persian spondaic words have previously been reported. The present study aimed to design a BMLD test application using Persian spondaic words at different levels of speech recognition.

Methods

Participants

This cross-sectional study was conducted on 20 people (10 males) aged 18–25 years (mean age=21.55±2.37 years) with normal hearing referred to the Audiology Clinic of the School of Rehabilitation of Shahid Beheshti University of Medical Sciences. A convenience sampling method and diagnostic tolerance screening tests were used to select the participants. The test included medical history recording, otoscopy, pure tone audiometry, tympanometry, and dichotic digit test. The audiometric assessment, behavioral auditory processing and tympanometry tests were performed using an audiometer (Madsen Astera2, GN Otometrics, Denmark) and a tympanometer (AZ-26, Interacoustics, Denmark). The medical history recording included a number of questions about the general health, use of medications, and exposure to occupational noise. After the interview and otoscopy, individuals with complaints about outer and middle ears abnormalities, otologic surgeries, neurological disorders or exposure to occupational noise/acoustic trauma were excluded from the study. For the remaining individuals, pure tone audiometry test was performed in an acoustic chamber. Those with pure tone thresholds <20 dB (at frequency range of 250-8000 Hz) were excluded from the study. Finally, the dichotic digit test was performed which is used to assess the central auditory processing [13, 14, 18]. Individuals with less than 95% of correct answers in both ears were excluded [14]. The individuals who met the inclusion criteria continued the assessment process and underwent the MLD test using the designed application.

The binaural masking level differences test application

The BMLD test application has the ability to evaluate for pure tone and speech stimuli in all phase angles with an accuracy of one degree at an intensity level of 1 dB. The application has two parts including the code section and the graphical user interface (GUI). The code section consists of 1846 lines of codes in Windows-specific executable files. MATLAB version R2019b software was used to design the GUI, and Photoshop software was used to design the GUI items and images. Figure 1 shows a view of the designed BMLD test application. The designed application has the ability to evaluate the BMLD using a laptop or audiometer at an intensity level of 1 dB and at the desired phase angle (-π to +π). Moreover, it can evaluate the BMLD with pure tones at the frequency range of 20-20,000 Hz with the desired duration and also with arbitrary speech stimuli as well as an ability to import words in a group. Other features of the application included: Auto truncation and arbitrary deletion threshold to cut time delays before and after recorded words, pure tone and speech normalization with arbitrary root mean square (RMS) as an indicator of signal tone measurement, production of NBNs and speech noise with custom filters, production of BBNs with uniform distribution (rand function) and normal distribution (Rerand function), illustrating the signal and noise waveforms in nine different conditions as monaural and binaural, exporting the waveforms in pdf, tiff, jpg, and png formats, and illustrating the signal and noise curves at different intensity levels. This application is able to change the phase of input signals (speech, noise, or both) selectively in a range of 0 to 180 degrees (with an accuracy of 1 degree). It should be noted that the audio output is provided using the Mono stereo interface and received using a TDH-39 headphone; meanwhile, there was the possibility of changing the signal and noise intensity. The output sound was calibrated using a sound level meter (B&K 2250 Light) and a 6-cc coupler (Brüel

Table 1. The comparison of masking level difference values between males and females in different conditions for speech and tonal stimuli (n=20)

Stimulus	Condition	Gender	Median	Mean (SD)	(t/Z)	p
Speech	SoNo-SπNo	Male	4	6.70 (1.64)	0.197	0.216+
		Female	5	6.90 (1.57)		
	SoNo-SoNπ	Male	3	4.30 (1.68)	0.722	0.482*
		Female	3	4.60 (1.83)		
500 Hz signal	SoNo-SπNo	Male	9	10.80 (1.25)	0.244	0.874*
		Female	9	10.20 (0.97)		
	SoNo-SoNπ	Male	5	5.80 (1.54)	0.380	0.667*
		Female	5	6.40 (1.39)		

+ Independent t-test, * Mann-Whitney test

& Kjær Sound & Vibration Measurement A/S DK-2850 Naerum, Denmark). To calibrate the output, first the headphones were connected to the 6-cc coupler and then the coupler was attached to the sound level meter.

Masking level difference assessment

In the first stage, 40 standard Persian spondaic words with equivalent syllables (including phonemes at low-, medium-, and high-frequency ranges) were selected and recorded (in the mono condition). The words were spoken by a professional man Persian-speaking talker. Then, the recorded spondaic words were added to the sound processing panel of the designed BMLD test application. It should be noted that the standard list of words used in English for this test was those in List 1 of CID W-1 spondaic words [22]. Afterwards, each word was played ten times and the sound was analyzed at a high sampling rate, which showed both the maximum and average intensity of each stimulus. We used the average intensity in presenting the words. The correction factor required for the output intensity of each word in the application was coded and applied, and then the relevant data were recalibrated to ensure the speech stimulus intensity alignment. For threshold measurement in different phase conditions with tonal stimulus, reduction steps to increase the test accuracy to 1 dB were considered. It should be noted that, due to the variable amplitude of BBNs (speech and noise), the possibility of content standardization using RMS=1 was determined in the application to control possible fluctuations and content uniformity. The laptop used for the MLD test was Acer model 5742G, equipped with a sound card. Based on the purpose of the test, the phase conditions (SoNo, SπNo, and SoNπ) and the signal and noise intensity were determined and the stimuli were presented in a binaural manner. Due to the normal hearing ability of participants and the speech contents, the test was performed at the most comfortable level (60 dB) and the noise was presented at a constant effective

Table 2. Test-retest reliability of speech and tonal stimuli in different conditions (n=20)

Stimulus	Condition	ICC	p
Speech	SoNo	0.80	0.047
	SπNo	0.81	0.041
	SoNπ	0.91	<0.001
500 Hz signal	SoNo	0.87	0.015
	SπNo	0.82	0.026
	SoNπ	0.89	<0.001

ICC; intraclass correlation coefficient

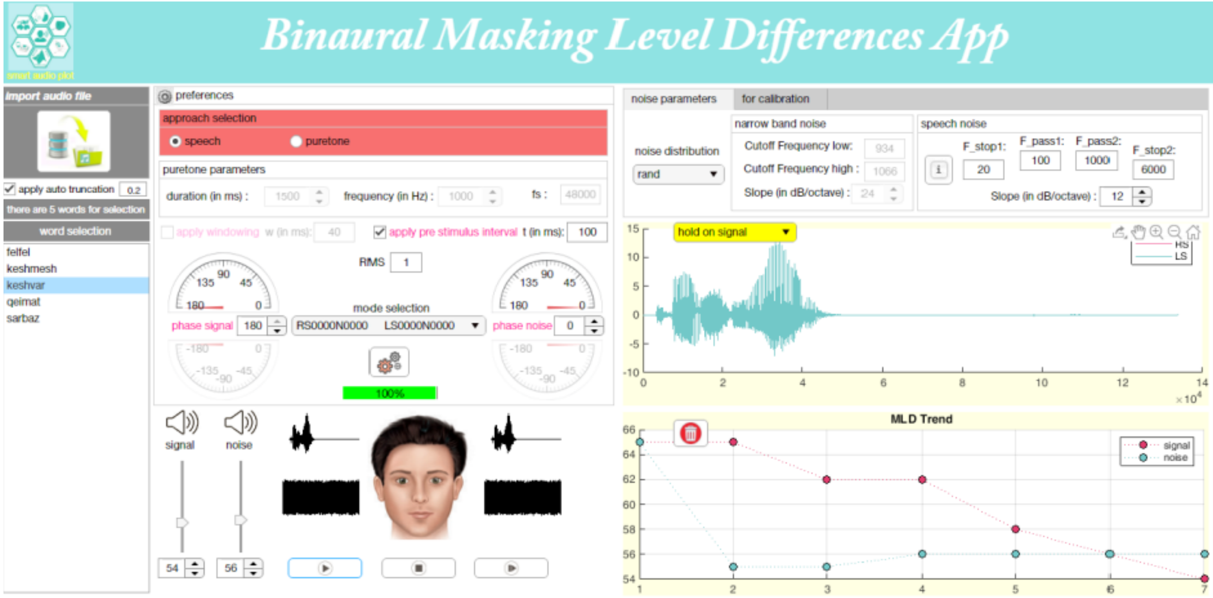

Figure 1. Binaural masking level differences software

masking level of 60 dB. The presentation intensity of the spondaic words was reduced by 2 dB until the speech recognition threshold is achieved [18]. After measurement of thresholds in three different phase conditions of speech and noise stimuli, MLDs were calculated by subtracting SπNo from SoNo and SoNπ from SoNo. The above steps were performed using a pure tone of 500 Hz. In order to examine test-retest reliability, all the mentioned steps were repeated after one week.

Data analysis

To examine the test-retest reliability of the application, the intraclass correlation coefficient (ICC) was used. For comparing the MLD values with different formulas (SoNo-SπNo and SoNo-SπNo) for speech and tonal stimuli based on gender, independent t-test and Mann-Whitney U test were used. To compare MLD values between different conditions (SoNo-SπNo and SoNo-SoNπ) for speech and tonal stimuli, Wilcoxon statistical test was used. To investigate the correlation between the MLD values for speech and tonal stimuli (in two conditions), Spearman correlation test was used. Statistical analyses were performed in SPSS v.17. A $p<0.05$ was considered as the significance level.

Results

The results of the central tendency index, dispersion, and comparison of MLD values in the subjects in different conditions (SoNo-SπNo and SoNo-SoNπ) for speech and tonal stimuli based on gender are presented in Table 1. There was no significant difference between males and females under any conditions (p>0.05(. There was

Table 3. Spearman correlation coefficient between the masking level difference values for speech and tonal stimuli in different conditions (n=20)

		SoNo-SπNo				SoNo-SoNπ			
		Speech		500 Hz signal		Speech		500 Hz signal	
Condition	Stimulus	r	p	r	p	r	p	r	p
SoNo-SπNo	Speech	-	-	0.343	0.139	0.672*	0.001	–0.140	0.556
	500 Hz signal	0.343	0.139	-	-	0.400	0.081	0.208	0.380
SoNo-SoNπ	Speech	0.672*	0.001	0.400	0.081	-	-	–0.140	0.556
	500 Hz signal	–0.140	0.556	0.208	0.380	–0.140	0.556	-	-

* Correlation is significant at the 0.01 level (2-tailed)

a significant in MLD values of speech and tonal stimuli between SoNo-SπNo and SoNo-SoNπ conditions (z=-3.535, p≤0.001; z=-3.936, p≤0.001), where the MLD values for speech and tonal stimuli under SoNo-SπNo condition (6.85, 10.50 dB) was greater than under SoNo-SoNπ condition (4.43, 6.12 dB). Moreover, there was a significant difference between MLD values of speech and tonal stimuli in SoNo-SoNπ and SoNo-SπNo conditions (z=–3.943, p≤0.001; z=-3.434, p≤0.001), where the MLD value of tonal stimuli was more than that for speech stimuli.

The ICC results are presented in Table 2. The thresholds in different phase conditions for speech and tonal stimuli were highly reliable (p<0.05). The correlation between the MLD values using speech and tonal stimuli was not significant under any conditions (p>0.05) (Table 3).

Discussion

In the present study, the results showed that thresholds in all phase conditions (SoNo, SπNo, and SoNπ) for speech and tonal stimuli were highly reliable (p>0.05). There was no significant difference between the MLD values in males and females (p>0.05), but there was a significant difference in MLD values between the SoNo-SπNo and SoNo-SoNπ conditions (p<0.05). The MLD values under the SoNo-SπNo condition was higher than under the SoNo-SoNπ condition. This finding is consistent with the results of other studies [6, 9, 19, 20]. There was a significant difference between the MLD values of tonal and speech stimuli (p<0.05), where the MLD value of tonal stimuli was higher than that of speech stimuli. This finding is consistent with the results of other studies [14, 16, 21, 22].

The analysis of the MLD values (averages) for speech and tonal stimuli under SoNo-SπNo and SoNo-SoNπ conditions, showed that the values obtained in the present study are close to the MLD values reported in the studies conducted by Mendes et al. [20], Wilson et al. [22] and Johansson and Arlinger [18]. By averaging, comparing and subtracting the thresholds in the SoNo and SπNo conditions for 500 HZ signal, a study reported an average MLD of 10.83 dB [21] which is very close to the average value (10.50 dB) obtained in the present study. In the present study, the average values of MLD under SoNo-SπNo and SoNo-SoNπ conditions for Persian spondaic words were 6.85 and 4.45, respectively, which is very close to those reported by Wilson et al. [22] and Johansson and Arlinger [18] for English and Swedish spondaic words (7.2 and 5.7, respectively).

The strengths of the present study were the use of tonal and speech stimuli, the evaluation of test-retest reliability for the output of the designed application, and using both possible conditions to calculate the MLD values (SoNo-SπNo and SoNo-SoNπ). Due to the importance of performing BMLD test with speech stimulus, it is necessary to pay attention to the central auditory processing and binaural interactions in this test. When a speech stimulus is used to assess the central auditory processing, it is processed and represented in much wider areas of the human auditory system. The linguistic, syntactic, and phonetic aspects of speech stimuli can add complexity to these auditory processes. Considering the principles related to the role of the auditory brainstem (especially the lower brainstem) in decoding auditory information as well as the phenomenon of release from masking and comparing the results of different studies, our results are in accordance with the phenomenon of release from masking for tonal stimuli from the lower brainstem and indicate the role of the lower brainstem in the occurrence of release from masking for speech stimuli. Given the difference between the MLD values of speech and tonal stimuli (lower MLD for the speech stimuli) and considering the processing complexities of speech stimuli, it can be said that other brain areas, in addition to the lower brainstem, probably play a role in the release from masking for speech stimuli. Therefore, it should be addressed with caution.

In this study, we faced difficulty determining the MLD values using speech materials due to their complexity and the spectral and physical alterations as well as standardization and calibration in terms of intensity compared to pure tone; therefore, in designing the BMLD test application, the RMS was set at 1. Moreover, in order to calibrate and select the appropriate speech stimuli to perform the test, a sound level meter with high a sampling rate, online monitoring, and peak equivalent index was used. Furthermore, due to the alterations in the spectral and physical aspects of speech stimuli, 2 dB-steps was used to achieve the speech recognition thresholds of the participants. To perform the MLD test using tonal stimuli, 1 dB-steps were used; therefore, if it is possible to achieve speech recognition thresholds with a 1 dB precision. The MLD test using the speech of Persian-speaking people has higher reliability and more accurate values.

Conclusion

The designed binaural masking level difference test application using speech stimuli in Persian and pure tone has similar results compared to conventional masking level difference tests for other languages; therefore, this application can be used in audiology clinics in Iran to perform the masking level difference test.

Ethical Considerations

Compliance with ethical guidelines

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Authors' contributions

MA: Study design, acquisition of data, interpretation of the results, statistical analysis, drafting the manuscript; MRS: Interpretation of the results, drafting the manuscript and statistical analysis.

Conflict of interest

The authors declared no conflicts of interest.

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