

Sound Localization Test in Presence of Noise (Sound Localization Test) in Adults without Hearing Alteration

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Abstract

Introduction Even people with normal hearing may have difficulties locating a sound source in unfavorable sound environments where competitive noise is intense.

Objective To develop, describe, validate and establish the normality curve of the sound localization test.

Method The sample consisted of 100 healthy subjects with normal hearing, > 18 years old, who agreed to participate in the study. The sound localization test was applied after the subjects underwent a tonal audiometry exam. For this purpose, a calibrated free field test environment was set up. Then, 30 random pure tones were presented in 2 speakers placed at 45° (on the right and on the left sides of the subject), and the noise was presented from a 3rd speaker, placed at 180°. The noise was presented in 3 hearing situations: optimal listening condition (no noise), noise in relation to 0 dB, and noise in relation to -10 dB. The subject was asked to point out the side where the pure tone was being perceived, even in the presence of noise.

Results All of the 100 participants performed the test in an average time of 99 seconds. The average score was 21, the medium score was 23, and the standard deviation was 3.05.

Conclusion The sound localization test proved to be easy to set-up and to apply. The results obtained in the validation of the test suggest that individuals with normal hearing should locate 70% of the presented stimuli. The test can constitute an important instrument in the measurement of noise interference in the ability to locate the sound.

Keywords

- ▶ hearing
- ▶ audiology
- ▶ noise
- ▶ localization of sound source
- ▶ sound localization

Introduction

The ability to locate a sound source is present in human beings with normal hearing from birth. It is a primitive capacity that is triggered at the level of the lower brainstem.¹ It is directly related to the ability to obtain binaural and three-dimensional sound information.²

Knowing the direction from which the sound comes is important for the individual to orient himself in space, to

prevent danger (such as traffic danger), and to turn his attention to important daily sounds.

The brain compares the information received by the ears, such as the difference between the sound receiving time and its intensity in the ears. These two indicators allow determining the sound location and directional transfer.³

Even individuals with normal hearing tend to have difficulties locating a sound source in unsuitable environmental conditions (that is, noisy environments), and this situation is aggravated when the person has some type of hearing loss.^{4,5}

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Locating the sound source becomes a problem^{6,7} to people with unilateral or asymmetric hearing loss. There are cases in which the difficulties with listening in different daily situations generate psychological alterations. These alterations may seem disproportionate to the level of acoustic hearing residual loss.^{8,9}

In these cases, a hearing aid has been a widely used resource. However, its use does not always result in a specific improvement of the localization ability.¹⁰ As examples, we cite the cochlear implants in unilateral hearing loss,¹¹ the use of prostheses anchored in the bone in unilateral losses,¹² the cross-system of hearing aids,¹³ and even conventional prostheses adapted to severe asymmetric hearing losses.¹⁴ In all cases, assessing the ability to locate a sound source can be a good resource for regulating the device¹⁵ and for checking the benefits of the device fitting, especially if there is a competitive noise.

Thus, evaluating the capacity of locating the sound has been a constant demand in speech therapy. Tests were developed for this purpose, such as the Spatial Sound Perception Analyzer (ASPE, in the Portuguese acronym)¹⁶ and the sound localization test,¹⁷ both involving laboratories with several speakers for multidirectional sound evaluation. Although they are effective in their objectives, the reproduction of many tests is unfeasible in clinical settings, such as medical or speech-therapy clinics. That is because they require a lot of equipment, which makes the procedure costly.

Based on these assumptions, as well as on the purpose of evaluating the benefits of hearing aids on the locating ability, the sound localization test was developed (sound localization test in presence of noise). It is an accessible and easy to apply test that was validated in a pilot study. Subsequently, it was tested in individuals with normal hearing. Therefore, the purpose of the present study is to describe, validate and establish the normality curve of the sound localization test in subjects with normal hearing.

Materials and Methods

This is a clinical study with experimental aspects. It is self-controlled to ascertain the accuracy of the sound localization test. The study was approved by the Ethics Committee of the institution under the number 0051/14, and data collection occurred between February and April 2015.

A total of 103 subjects participated in the present study; 3 of them were excluded from the study because they presented hearing loss in a tonal audiometry exam. Considering the criteria proposed by the Federal Council of Speech Therapy (CFFa, in the Portuguese acronym),¹⁸ all of the 100 subjects that comprised the sample had normal hearing. Of the total sample, 17 subjects were men and 83 were women, aged between 19 and 64 years old. The average age was 34.1 years old, with a standard deviation (SD) of 10.8 years. The participants were randomly selected from a waiting room at a clinic. After receiving orientation about the study, they signed an informed consent form.

To perform the present research, the following device was specially developed: a booth with a two-channel audiometer, a three-output free field device, as well as a noise source attached to the audiometer, and a pure tone localization test.

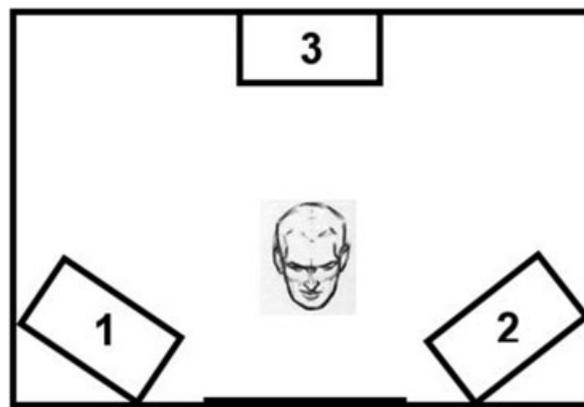


Fig. 1 Positioning of the acoustic speakers in the booth. (1) Speaker placed at 45° to the right of the subject. (2) Speaker placed at 45° to the left of the subject. (3). Speaker placed at 180°, with noise.

The pure tones were randomly presented in the side speakers, sometimes to the left, other times to the right of the subject being tested. All of the equipment was calibrated according to the norms of the CFFa.¹⁹

Test Setting

The test setting consisted of an audiometric booth containing 2 speakers located at 45° (to the right and to the left of the subject being tested), which are routinely used in the speech-therapy clinic for free field evaluation, and a third speaker, or third channel, installed at 180°. The speakers were distributed in a way to allow a better perception⁵ and practical organization of the booth, as shown in **Fig. 1**.

The free field (CL30-V, Oto Sonic, São Paulo, SP, Brazil) used was model without a serial number, calibrated on October 17, 2014, with the certificate number 415-2013F, according to ISO8253-3 and IEC645-2; 1993. The standards were met by using the following devices for calibration: Sound Pressure Meter Larson Davis, Mod 824 (Larson Davis, Depew, NY, USA), serial number 824A2867 (Certificate number 50 381/2014); Sound Calibrator Larson Davis, model CAL 250 (Larson Davis, Depew, NY, USA), serial number 4128 (Certificate No: 50 378/2014); and Microphone Larson Davis, Mod 2575 (Larson Davis, Depew, NY, USA), serial number 1698 (certificate number 50 379/2014).

The third channel for the free field was developed to control and amplify a third sound source used as a competitive signal inside the booth. It has a circuit consisting of the following: an input preamplifier, a calibration circuit with gain adjustment from 0 to 40 dB, a linear output attenuator with 5 dB steps and a total range from 0 to 100 dB SPL, a T-class digital power amplifier with 50 watts, a microchip micro controller, model free field (PIC18F2550, Master Audiology, Curitiba, PR, Brazil), a display of 2 lines by 20 characters, and a keyboard. The third channel equipment was calibrated on July 31, 2014, with the certificate number 425a-2014-F, according to ISO8253-3 and IEC645-2; 1993. The standards were met by using the following devices for calibration: Brüel & Kjaer, Mod. 2250 (Brüel & Kjaer Sound & Vibration Measurement A/S, Naerum, Denmark), serial number 3006245 (Certificate number CBR1400264/2014); Acoustic Calibrator Brüel & Kjaer, mod. 4231 (Brüel & Kjaer

Sound & Vibration Measurement A/S, Naerum, Denmark), serial number 3007539 (Certificate number CBR1400268/2014); and Larson Davis Microphone, Mod. 2575 (Larson Davis, Depew, NY, USA), serial number 2119 (Certificate number 60.381/2014).

The operation of the system allows the adjustment of the external sound source. In the present project, the researchers used a Samsung cellular phone (Galaxy CS, Samsung, Seoul, South Korea) with the Sound Generator (SG) application. The application was configured to generate white noise (broad band). The professional can calibrate the correct level of the signal, used by the calibration mode of the equipment, by displaying the signal and by adjusting it to 0 dB in the volume unit (VU). Once set, the signal can be displayed at the level selected in the attenuator through the stimulus button that turns the noise on or off.

Test

The sound localization test comprised 30 stimuli (pure sounds) that were presented in the free field.

The synthesis and the recording of the test sounds were performed using the Sony Sound Forge 11 sound editing software (Sony Corporation, Tokyo, Japan). Sounds at 1,000 Hz at a level of 0 dB were generated in uncompressed .wav files to ensure fidelity and to avoid distortions and cross-referencing data from one channel to another.

The tones used had a duration of 1 second, and they respect the rising and falling times commonly used in the presentation of stimuli of audiometers (100 ms, according to IEC 60645-1), and the silence breaks between the tones had a duration of 2 seconds.

Four different test files were created; one for training, and the others for assessment, in which the stimulus sequence contains 10 presentations of the sounds. They are presented to the right or to the left of the subject. In conjunction with the sound sequences, follow-up guides were generated so that the examiner knows the sequence and the sides of the presentation, and is able to validate the responses.

Data Collection

All of the subjects filled out an identification form and were submitted to an otoscopy and to a threshold tonal audiometry to determine their auditory thresholds. After the audiometry, those who had hearing within the normal standards were submitted to the sound localization test.

The subject being tested was sitting in the center of the booth without headphones. He listened to 30 stimuli (pure

tones) that randomly came from the speakers located at 45°. The individual was instructed to pay attention to the whistle sound and to point to the right or to left side, according to where the sound came from. Background noise should be ignored. Then the training was performed with a sequence of 10 stimuli.

The test was applied in 3 situations: a) 10 pure tone stimuli, alternated between the right and left speakers, presented without competitive noise (control); b) 10 pure tone stimuli, alternated between the right and left speakers, presented in a signal-to-noise ratio of 0 dB (study); c) 10 pure tone stimuli, alternated between the right and left speakers, presented in a signal-to-noise ratio of - 10 dB (study).

The pure tone was presented at 40 dBNS, that is, 40 dB above the tri-toned average obtained in the tone threshold audiometry. In the signal to noise ratio of 0 dB, the whistle and the noise were set at the same intensity. At the signal-to-noise ratio of - 10dB, the noise was 10 dB louder than the stimulus (pure tone), the stimulus was presented in the field system (speakers at 45°), and the competitive noise was presented in the third channel (at 180°).

Data Analysis

The data were noted in the protocol of self-register (► **Table 1**) and analyzed statistically. For comparison purposes, the Student *t*-test was used at a significance level of 0.05.

The following variables were analyzed and compared: noise-free test results (control) with the results of the test with noise at 0 dB and at - 10 dB (study). The test results also took into consideration the interference of the age factor. Two age groups were analyzed, considering the wide age range of the sample. Notice that G1 was formed by subjects < 40 years old, and G2 by people aged ≥ 40.1 years old. Finally, the test results were analyzed according to gender.

Results

A total of 17 men and 83 women participated in the present study. All of them had normal hearing, considering the criteria proposed by the CFFa.¹⁸ All of the participants easily understood the requested task, and the average duration of the test was 99 seconds, considering the application of the 3 steps.

The use of sound stimuli at 40 dB SPL ensured that all subjects were listening to both sounds, that is, to the stimuli and to the background noise.

The descriptive results considering the location of the sound source with and without the presence of noise are

Table 1 Sound localization test answer sheet

| Tri-toned Average | | Pure Tone of 1,000 Hz | | | | | | | | | |
|-------------------|------------------|-----------------------|----|----|----|----|----|----|----|----|----|
| _ dB | | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
| Absence of noise | | R | R | L | R | L | L | L | R | R | L |
| Presence of noise | relation 0 dB | L | R | R | L | R | R | L | L | L | R |
| | relation - 10 dB | L | R | L | L | R | R | L | R | L | R |

Abbreviations: L, the sound comes from the speaker to the left of the subject; R, the sound comes from the speaker to the right of the subject.

Table 2 General descriptive data acquired in the sound localization test ($n = 100$)

| Listening conditions | Minimum number of correct answers | Maximum number of correct answers | Average correct answers | Median | Standard deviation |
|-----------------------------------|-----------------------------------|-----------------------------------|-------------------------|--------|--------------------|
| With no competitive noise | 1 | 10 | 7.24 | 9 | 3.04 |
| Competitive in relation to 0 dB | 1 | 10 | 7.08 | 7.5 | 3.05 |
| Competitive in relation to -10 dB | 0 | 10 | 7.03 | 8 | 3.08 |

described in ►Table 2, where it is possible to verify that the presence of noise did not cause a reduction in performance.

The results of the test considering the interference of the age factor are described in ►Table 3, and the test results evaluating the outcome by gender are presented in ►Table 4.

No significant difference was observed ($p > 0.05$) in the Student *t*-test, at the significance level of 0.05 (5%), among the results obtained from both groups in relation to the variables age and gender.

Discussion

The ability to locate a sound source connects an individual to the environment in which they live.²⁰ It allows three-dimensional perception of sounds, which facilitates speech intelligibility. Therefore, it is an area of study in audiology, since people with different hearing losses, including unilateral loss, complain of comprehension difficulties, especially in noisy environments.²¹

Evaluating this ability has been a challenge to speech therapists. The tests developed in the academia^{16,17} are often not feasible because they demand a sophisticated laboratory,

consisting of several speakers, all of them installed in a free field, which raises the costs of these studies.

In daily life, noise can affect people from different angles. However, a test that reproduces these conditions is not feasible in practical speech therapy due to the necessary cost and time. Thus, the noise proposed by the test described here occurred at an angle of 180°.

The test proposed presented low cost, easy setup and application, in addition to using standardized material (recorded), which ensured the reliability of the results.^{22,23}

When analyzing the mean of the correct answers of the subjects (►Table 1) in the sound localization test, it was observed that there was no significant difference when considering the conditions of listening without noise and with competitive noise. The scores obtained were practically identical, ranging from 7.03 to 7.24. Thus, in individuals with normal hearing, it is expected that the subjects correctly locate 70% of the presented stimuli.

In people with symmetric bilateral hearing, the ability to locate the sound source develops naturally, resulting from the comparison between the arrival times of the stimulus in the auditory pathways within the brainstem.²⁴

Table 3 Sound localization test results according to age ($n = 100$)

| Variable | < 40 years old | | | ≥ 40.1 years old | | | p-value |
|----------------------------------|----------------|-------------------------|----------------|------------------|------|--------------------|---------|
| | n | Average correct answers | Standard curve | n | Mean | Standard deviation | p |
| With no competitive noise | 72 | 7.19 | 3.05 | 28 | 7.29 | 3.02 | 0.4415 |
| Competitive in relation to 0 dB | 72 | 7.02 | 3.06 | 28 | 7.09 | 3.07 | 0.4592 |
| Competitive in relation to 10 dB | 72 | 6.99 | 3.10 | 28 | 7.05 | 3.09 | 0.4654 |

Statistical analysis: Student *t*-test.
Level of significance: 0.05.

Table 4 Sound localization test results according to gender ($n = 100$)

| Variable | Female | | | Male | | | p-value |
|-----------------------------------|--------|-------------------------|----------------|------|------|--------------------|---------|
| | n | Average correct answers | Standard curve | n | Mean | Standard deviation | |
| With no competitive noise | 83 | 7.22 | 3.04 | 17 | 7.27 | 3.01 | 0.4754 |
| Competitive in relation to 0 dB | 83 | 7.05 | 3.06 | 17 | 7.08 | 3.06 | 0.4853 |
| Competitive in relation to -10 dB | 83 | 7.00 | 3.08 | 17 | 7.04 | 3.07 | 0.4806 |

Statistical analysis: Student *t*-test
Level of significance: 0.05.

When the age variable was tested, no significant difference between the subgroups was found, even with the evidence that cochlear degeneration and structural changes in the auditory nerve and central pathways in the brainstem are associated with the aging process.²⁵

The same results were observed when the gender was tested as the variable. Studies indicate that men have better location abilities than women;^{26,27} however this difference was not significant in the study.

It can be inferred, therefore, that the normality standard of the sound localization test is 70% correct answers, for people with normal hearing, regardless of age or gender.

The test described in the present study can be a valuable tool in the investigation of auditory processing, in the selection and recommendation of hearing aids, as well as in the performance assessment of patients who use sound amplification and implantable prostheses. Currently, this type of investigation is based on the subjective perception of the individual, taking into account questionnaires of performance verification.²⁸

Conclusion

The sound localization test proved to be practical in organization and execution. The results obtained in the validation of the test suggest that individuals with normal hearing should locate 70% of the presented stimuli. Background noise, age and gender do not interfere with the result. This test can be an important tool in the appreciation of noise interference in the sound locating ability.

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