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Spatial Hearing

Nayiere Mansouri, Farzaneh Zamiri Abdollahi* and Meysam Nouri

Department of audiology, Tehran University of Medical Sciences, Iran

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***Corresponding author:** Farzaneh Zamiri Abdollahi, Department of audiology, Tehran University of Medical Sciences, Iran,
Email: Audiology_zamiri@yahoo.com

Abstract

Spatial hearing is one of the most important and vital processing in the auditory system. It makes a base for higher level functions in the auditory system. In this paper some of these functions will be reviewed.

Keywords: Spatial Hearing; Auditory Localization; Speech Perception in Noise

Spatial Hearing and Auditory Localization

Spatial hearing is one of the incredible abilities of auditory system. It depends on binaural hearing and auditory localization [1,2]. Sound reaching two cochlea is delivered to central auditory system and in different stages signal from two ears are compared. One of the most important stages is superior olivary complex (SOC) which is the first stage in auditory system that binaural processing happens [3,4]. SOC neurons compare the time of arrival/phase and the intensity of signals between two ears. Based on interaural time/phase difference (ITD/IPD) and interaural intensity/level difference (IID/ILD), SOC encodes the sound source location. Other binaural nuclei in the auditory system work on this encoded signal from SOC and spatial hearing is sharpened and get more sophisticated (such as perception of moving sound source) [5,6]. In addition to central nuclei, the auditory cortex has a lot to do with spatial hearing and damage to the specific areas in the auditory cortex can destroy spatial hearing [7,8]. Furthermore, there are two parallel processing paths in the cortex for the auditory signals: one is "what" processing (content of the signal) and the other is "where" processing (spatial processing) [9-11]. This is indicative of spatial hearing importance. Auditory localization is a complex and advanced auditory function. We live in reverberations.

There are many echoes/reflections of the original sound source in the environment that reach to the ears with different delays, but we can localize the sound source with great precision. This is made possible by precedence effect. The auditory system uses only the first wave front to localize the sound source and other reflections are suppressed [12-14]. Studies have shown that this phenomenon is a high level process (from inferior colliculus to the cortex) [15]. but recent electrophysiologic studies on binaural interaction components (BICs) have shown that SOC might play a role as well because neurons in the SOC respond to the ITDs beyond ecologic range for the species. ITDs and ILDs help horizontal localization. For vertical localization, pinna and concha play an important role. Pinna has multiple folds and based on the elevation of the sound source, there are different reflections and the spectrum of the sound will change accordingly. These reflections make a notch in the sound spectrum which is dependent of the source vertical position, and central auditory system (dorsal cochlear nucleus) is able to detect that notch and encodes the vertical location of the sound source [16-18].

Spatial Hearing and Speech Perception in Noise

Spatial hearing can enhance speech understanding in noise/competition. There are many studies to support this notion [19-21]. When target sound source is spatially separate from other competing sound sources, a normal functioning auditory system enable us to have better speech recognition. So, a normal auditory system can gain benefit from spatial cues for better speech perception [22]. This improvement has been shown in studies on subjects with hearing aid and cochlear implant. Patients with two sensory aid show better speech perception in noise and competition [23-25]. It seems the best binaural processing in bilateral cochlear implant happens when two devices are implanted symmetric. Electrophysiologic studies using BIC support this finding. In fact, localization cues help auditory scene analysis and perception of one signal among multiple competing signals [26,27].

Plasticity of Spatial Processing

Spatial processing is highly plastic. In animal studies it is shown that blocking one ear and therefore changing binaural cues cause localization errors at first but after a while the animals are able to localize signals precisely. Then by removing ear plug again they show localization errors and again after a while their localization accuracy recovers. This plasticity is seen in both young and adult animals. So spatial plasticity remains even in adulthood [28-30]. Human studies have shown spatial processing plasticity as well. Few sessions of auditory localization in blind people under headphone or in the free field can significantly sharpen their localization skills and improve their quality of life and safety. Some studies show that sound localization is better in blind people than subjects with normal vision and they use echolocation for navigation in the environment [31-33]. In addition, auditory sound localization training can improve spatial hearing and speech in noise perception in children with (central) auditory processing disorder ((C)APD) . This plasticity again is seen not only in children but also in adults [20]. Spatial hearing in normal hearing infants develops gradually from birth [34].

Spatial Processing Disorder

Spatial processing disorder (SPD) is relatively young term. It refers to children who suffer from binaural processing of spatial cues, so they are not able to benefit from these important cues for separating target from competing signals. These children show listening difficulty in classrooms which are inherently noisy places. This disorder can easily affect their academic performance. It is mostly seen in children with history of recurrent otitis media [35-37]. SPD or any localization/ lateralization disorder can be seen in children with (C)APD. It can happen isolated or with other auditory processing disorders. It is emphasized that children suspected to (C)APD should be assessed in regard to their spatial processing skills and if there is a SPD, a deficit-specific training is mandatory to address this deficit [20,35,36].

Spatial Hearing Assessment

There are two well-known questionnaires for assessing spatial hearing and its related disability and handicap: The Speech, Spatial and Qualities of Hearing Scale (SSQ) and The Spatial Hearing Questionnaire (SHQ). The SSQ is composed of three subscales including speech hearing, spatial hearing and other qualities such as segregation of sounds, recognition, clarity/naturalness, and listening effort. SHQ focuses only on spatial hearing, covering areas of speech perception in quiet conditions, speech perception in spatial hearing situations, and localization of a sound source. It does not include questions on the quality of the speech or music [38-40]. There is a formal spatial test called spatial word in noise test (Farsi). This test performed under headphone. Monosyllabic words are presented randomly in presence of white noise in 7 different locations: -90, -60, -30, 0, +30, +60 and +90 degree azimuth. Child has to repeat the word and point to the spatial location that he hears it [20]. One formal and advanced spatial test is listening in spatialized noise-sentence/universal (LiSN-S/U) which is available in English language. This sophisticated test can easily and precisely measure child's ability in using spatial cues for understanding target speech from competing ones [41,42].

Conclusion

Spatial hearing is one the most important auditory processing that affects speech understanding in noise. There is an absolute need for appropriate tests for its evaluation. This processing shows great plasticity by training.

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