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RESEARCH ARTICLE

Normative variation of auditory stream segregation in adults

Fatemeh Moghadasi Boroujeni[1], Masoumeh Rouzbahani[1*], Fatemeh Heidari[1], Mohammad Kamali[2]

[1]- Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran

[2]- Department of Basic Sciences, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran

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Abstract

Background and Aim: Human beings receive a variety of sounds in their everyday lives. These sounds are generated by different sources, and are heard simultaneously or with a small time sequence. A characteristic of the auditory system is its ability to analyze complex sounds, and to make decisions about the source of each constituent part of these sounds. The present study intends to assess normative variation of auditory stream segregation in adults.

Methods: This study has a cross-sectional design and was conducted on 40 normal adults with the age range of 18 to 35. Stimuli were presented in the form of pure tones A and B as ABA-ABA triplet pattern at the intensity level of 40 dBSL. The A tone frequency was selected as the basis at 500, 1000, and 2000 Hz. The B tone was presented with a difference of half to twelve and half semitones above the basis tone frequency in each phase.

Results: The fission boundary (FB) threshold was obtained in 500-2000 Hz. FB threshold was better in low frequencies than high frequencies. FB thresholds were independent of frequency when expressed as equivalent rectangular bandwidth (ERB).

Conclusion: Fission boundary threshold increased with the increase of frequency. When we used ERB, FB threshold was independent of frequency.

Keywords: Auditory stream segregation; fission boundary; attention; auditory object; auditory cortex

* **Corresponding author:** Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Shahid Shahnazari St., Madar Square, Mirdamad Blvd., Tehran, 15459-13487, Iran. Tel: 009821-22228051,
E-mail: rouzbahani.m@iums.ac.ir

Introduction

In our daily lives, we come across different sounds that often originate from various sources in the form of complex auditory signals. It is extremely important to properly perceive our surrounding environment and the acoustic sources that exist. To achieve such an understanding, one must be able to distinguish the sounds received and identify the source of each sound. The ability of the auditory system in distinguishing and classifying the surrounding sounds is referred to as auditory scene analysis (ASA) [1-4].

The surrounding events as perceived by the auditory system are called auditory objects [5]. For example, an individual walking in a park receives different sounds such as sounds of the birds, voices of people speaking, the sound of his or her own steps, etc. each comprising an auditory object. In fact, an auditory object represents the ability of the auditory system in discovering, extracting, segregating and grouping acoustic details [4,5].

Auditory scene analysis (ASA) may involve sequential or simultaneous grouping. The ability to sequentially organize acoustic elements is referred to as auditory stream segregation (ASS) which represents an essential aspect of ASA [6,7]. Defects in ASS leads to disorders in such skills as spatial orientation, understanding melodies, speech discrimination in noisy environment, etc. [8-10]. ASS is influenced by a variety of factors including spectral and temporal factors, order of acoustic patterns, and orientation [11].

One way to assess ASS is to determine fission boundary (FB) or temporal coherence boundary (TCB) threshold. The present study focuses on FB that compared to TCB exhibits greater stability while better reflecting the ability to segregate sequence of sounds in the form of one or more streams [12].

The study attempted to examine variation of ASS in normal adults using ASS psychoacoustic test.

Methods

This study had a cross-sectional design. It was performed on 40 normal individuals (18 males and 22 females). The participants' age was from 18 to 35 (mean 28.02, with SD=4.6). They voluntarily participated in the study. It should be noted that all the participants had the following characteristics:

1) They had a high school diploma degree or above, 2) Their mother tongue was Persian. They also lacked musical skills like playing any instrument and had not attended any music classes, 3) They had no record of suffering from any damage and injury affecting the auditory system such as metabolic diseases, progressive neural disorders, head trauma, memory disorders, cognitive disorders, and progressive sclerosis, 4) They had not taken any anti-depressant and psychological drugs, 5) They had normal peripheral hearing (the range of threshold -10 to +15 dBHL in the 250-8000 Hz, tympanogram with the peak pressure of +50 to –100 dapa, and the static compliance of 0.3 to 1.6 millimho) [13].

In this study the focus was on FB threshold. The stimuli used in this section were designed in the triplet pattern of ABA-ABA [2]. The "-" indicates the silence between triplets (100 ms). The duration of A and B stimuli is 100 ms (the 10 ms rise and fall time and the time between them in each triplet is 20 ms) [12,14].

The intensity level of A and B tone was considered as similar. Due to the effect of the increase in intensity on the FB value [12], the stimuli were presented in the intensity level of 40 dBSL in binaural form. The A tone frequency was selected as basis in each triplet with the values of 500, 1000 and 2000 Hz. The B tone was presented with the difference of a half to twelve semitones above the basis tone frequency in each phase. Each block contains 22 triplets. At the end of each block, if the subject hears the stimuli as a continuous sound, he or she raises his/her right hand, but if (s)he hears them as two separate sounds, (s)he raises his/her left hand.

Fission boundary (FB) threshold is considered as the minimum frequency difference between A and B frequencies and in most cases an individual recognizes the stimuli as a stream with a characteristic of a fluctuating rhythm [15].

After determining the FB threshold based on the frequency difference, the FB threshold was calculated based on the difference between the number of equivalent rectangular bandwidth (ΔE) or ERB. E value was calculated according to the formula for each frequency as follows:

$$E = 21.4 \log (4.37F + 1)$$

These stimuli were constructed using MATLAB10 [11]. All the sounds were calibrated prior to the presentation.

Results

In this study, 40 normal adults in the age range of 18-35 (the mean age was 28.02 with SD=4.61) were examined. The FB threshold was calculated in the 500-2000 Hz of frequency range. Fig. 1 illustrates that the mean FB thresholds were better at low frequencies than high frequencies.

Fig. 2, illustrates that the mean fission boundary threshold was independent of frequency when expressed as ERB.

Discussion

The present study aimed to investigate variation

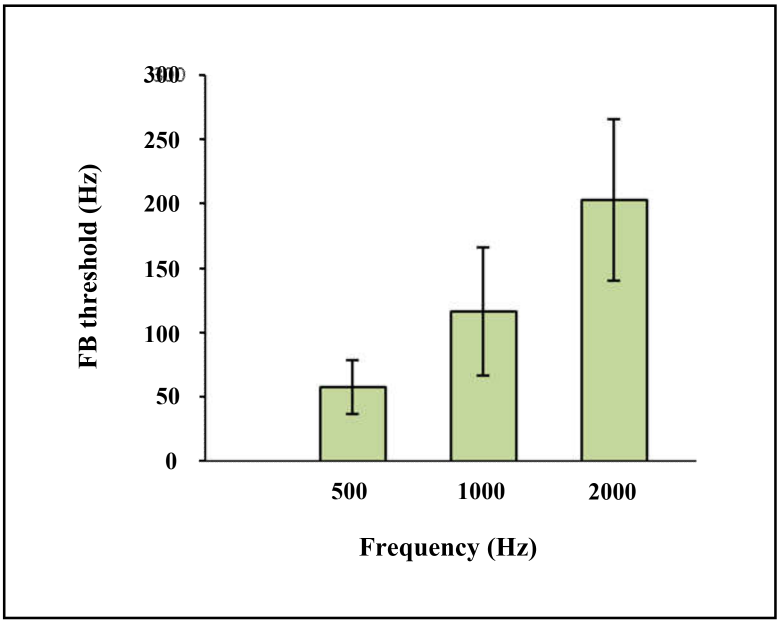

Fig. 1. Mean fission boundary threshold in normal adult at 500, 1000, and 2000 Hz. Fission boundary thresholds were better at low frequencies than high frequencies.

of auditory stream segregation in normal adults using ASS psychoacoustic test.

The fission boundary at the frequency range 500-2000 Hz was identified for 40 normal adults. As noted earlier, FB increased with the increase of frequency.

Two hypotheses have been put forth for ASS. The primitive ASS refers to bottom-up mechanism through which the auditory system performs streaming based on the signs existing in the auditory stimulus [16]. Studies in this field have argued that since the cochlear frequency is tuned to each stimulus based on the characteristics of that stimulus, the auditory system is capable of segregating auditory streams, and two stimuli may sound like a single stream if overlap of frequencies results in closely similar characteristics of the stimuli. In addition, studies have shown that the auditory area A1 is involved in ASS which is said to be originated from the cochlea given the tonotopic arrangement of this region [17]. On the other hand, the schema-based mechanism in perception of auditory streams refers to top-down pathways. Based on a requirement of a higher level of brain development, it is hypothesized that segregation of particular sounds, like familiar words, melodies, and voices of peers, occurs through learning. This segregation may occur in the form of attentive processes, e.g. trying to listen to a familiar sound in a noisy room, or pre-attentive processes, e.g. hearing someone call our name among the background sounds [16].

Most auditory neurons, above the cochlear nerve, can be selectively stimulated at different frequencies. This simple fact shows that some aspects of ASS can be seen at any point along the neural pathway (from the cochlear nerve to A1) with frequency selectivity. When stimulated by the two tones A and B with small difference in frequency, the neuron responds to both tones, leading to perception of an oscillatory rhythm. As this frequency gap increases, the neuron only responds to the tone A [18]. Evidently, under primitive ASS mechanism for streaming at a smaller frequency gap, sharper selective tuning to the stimulus results in perception of two streams.

Auditory streaming may be strongly affected by attention. Schema-based processing of auditory streaming occurs in both attentive and pre-attentive forms [16].

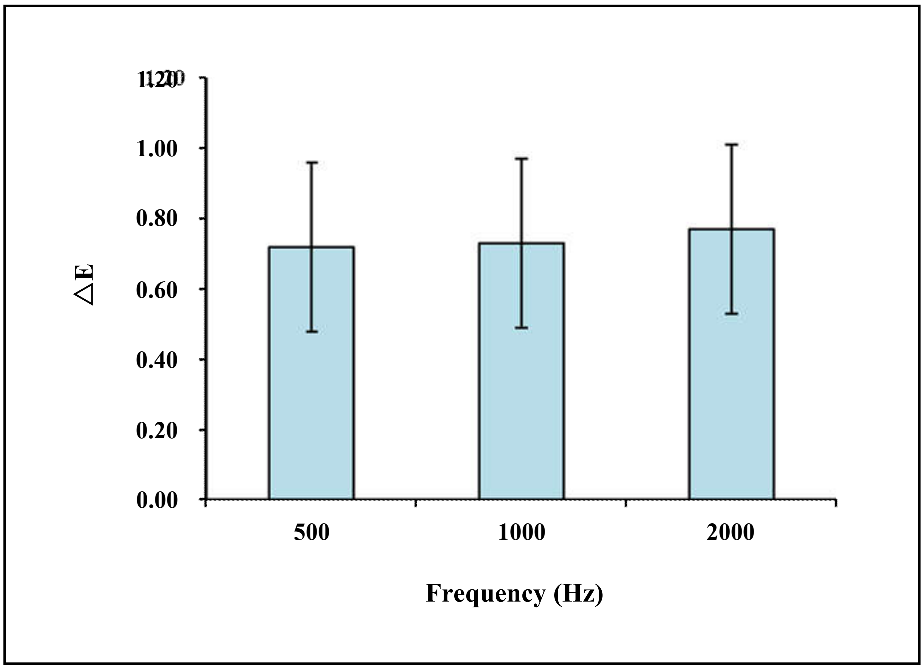

Fig. 2. Mean fission boundary threshold in normal adult at 500, 1000, and 2000 Hz. Fission boundary thresholds were independent of frequency when expressed as equivalent rectangular bandwidth.

Both auditory and non-auditory areas are involved in auditory stream processing. Cusack [19] demonstrated that perception of two auditory streams is associated with the activity of three regions of intraparietal sulcus (IPS). Since streaming varies over time for a sequence of sounds, IPS activities also vary through the same sequence depending on whether an individual is hearing one or two streams at that time. He argued that IPS may be involved in some aspects of supra-modal perceptual organization [18].

A1 is involved in the streaming process, and the area is more sensitive in responding to lower frequencies compared to the higher ones [20]. Lower FB for lower frequencies may be caused by higher A1 sensitivity while responding to lower frequencies compared to its sensitivity while responding to higher frequencies.

These results were confirmed by previous studies. Bayat et al. [11] compared FB threshold between normal and mild SNHL individuals. They concluded that, differences between two groups increase with the increase of frequency. At the first glance, our results were inconsistent with findings of Rose and Moore [7,12]. They expressed that FB threshold was independent of frequency when expressed as ERB. When the FB threshold was calculated as ERB, we observed that FB threshold was independent of frequency.

It is likely that the FB is dependent on the frequency-to-place mapping in the cochlea. FB may show a match with the point where peaks of consecutive tones are separated by a fixed distance along the basilar membrane. This could be a commentary on the point that why ΔE values for subjects with normal hearing at different frequencies have been relatively consistent. E-scale is well matched with the scale of distance along the basilar membrane in subjects with normal hearing [21].

These results are in line with the model Beauvois and Meddis. This model predicts that in calculating FB, when the center frequency difference between successive tones is expressed based on the E value, ΔE amount is almost constant at different frequencies [22].

Conclusion

There was a direct relationship between

frequency and fission boundary (FB) threshold so that FB threshold increases with the increase of frequency. When the FB threshold was calculated as ERB, we observed that FB threshold was independent of frequency.

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