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Research article

Comparison of auditory stream segregation in sighted and early blind individuals

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HIGHLIGHTS

- Early blindness leads to lower fission boundary (FB) threshold.
- Basis of ERBs number, the FB threshold is independent of the frequency of the tone A.
- Visual deprivation can increase auditory stream segregation (ASS) capability.

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ABSTRACT

An important characteristic of the auditory system is the capacity to analyze complex sounds and make decisions on the source of the constituent parts of these sounds. Blind individuals compensate for the lack of visual information by an increase input from other sensory modalities, including increased auditory information. The purpose of the current study was to compare the fission boundary (FB) threshold of sighted and early blind individuals through spectral aspects using a psychoacoustic auditory stream segregation (ASS) test. This study was conducted on 16 sighted and 16 early blind adult individuals. The applied stimuli were presented sequentially as the pure tones A and B and as a triplet ABA–ABA pattern at the intensity of 40 dBSL. The A tone frequency was selected as the basis at values of 500, 1000, and 2000 Hz. The B tone was presented with the difference of a 4–100% above the basis tone frequency. Blind individuals had significantly lower FB thresholds than sighted people. FB was independent of the frequency of the tone A when expressed as the difference in the number of equivalent rectangular bandwidths (ERBs). Early blindness may increase perceptual separation of the acoustic stimuli to form accurate representations of the world.

1. Introduction

Human beings experience different auditory environments throughout their lives. In each auditory environment, an individual simultaneously or sequentially receives various sounds from different sources. The individual has to differentiate sounds received from different sources to attain adequate auditory and spatial understanding. The auditory system separates and groups components of different sounds and makes decisions about their sources. In auditory science, this phenomenon is referred to as auditory scene analysis [1–5].

Auditory scene analysis involves perceptive organization of the sound simultaneously or successively. The ability to organize sounds sequentially is called auditory stream segregation (ASS) [6,7]. Defects in ASS include difficulties in identifying the direction from which a sound originates, perceiving melodies, and others [8–13]. The fission boundary (FB) threshold can be used to assess ASS.

Carlyon [14] stated that primary auditory cortex contributes to the organization of streaming. Moreover, he points out that the role of non-auditory areas in streaming and attention also affects streaming. Streaming develops as a result of both bottom-up and top-down processes [15].

For an individual, an accurate perception of the surrounding environment and of the sound sources in the environment is essential, particularly when loss of a sense, such as vision, is involved.

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Blind individuals depend on other senses, such as hearing, to understand the environment.

Previous studies indicate that blind individuals possess better hearing than sighted individuals [16–25]. Blind individuals compensate for their vision deprivation by using their other senses more [22,26]. Even short-term visual deprivation in sighted individuals can improve frequency discrimination and sound location [23]. Blind individuals have better auditory capabilities in terms of orientation [17], auditory attention [18], discovery of peripheral sounds [19], acoustic stimulus frequency discrimination [16], judgement in auditory stimulus sequences [21], and verbal skills [20]. In a brain imaging study, auditory cortical activity was greater in early blind individuals than in sighted people [27]. Visual regions in blind people, including occipital cortex, are active during proccessing auditory stimuli [26,28,29]. However, most studies suggest neural plasticity in early blind individuals; but not all of them confirm the superior auditory skills of blind individuals. For example, Wan et al. [23] reported that blind individuals have better perceptive skills than sighted people, although this is not the case in higher-level processing skills, such as memorization.

Since blind individuals have a better tonotopic map than sighted individuals [30], we hypothesized that they have better ASS capability than sighted people. To our knowledge, this is the first report of ASS using spectral signs in early blind individuals. This study aimed to compare FB threshold in sighted and blind individuals via spectral aspects using an ASS as psychoacoustic and behavioral test.

2. Materials and methods

2.1. Participants

This comparative, cross-sectional study included 32 right-handed adults (aged: 18–35 years) with normal hearing sensitivity. Participation was voluntary, and all participants provided written informed consent. Control group contained 16 sighted individuals (eight males and eight females). Blind group included 16 early blind individuals who were age- and gender-matched with the control group. Also, all blind subjects had no reactivity to light, and the age of blindness onset was under 6 months after birth (11/16 were congenital blind).

Pure-tone audiometric threshold and tympanometry were meaured for two groups. All subjects had a normal hearing threshold (15 dBHL or better at octave frequencies from 250 to 8000 Hz in both ears) and normal type A tympanometry findings [31].

2.2. ASS measurement

Stimuli were as the pure tones A and B sequentially and in the triplet pattern of ABA–ABA. The "–" indicates the silence or the interval between triplets, which was set at 100-ms (Fig. 1). The duration of stimuli A and B was 100-ms (the 10-ms \rise and fall\ time and the time interval between them in each triplet was 20-ms) [32,33].

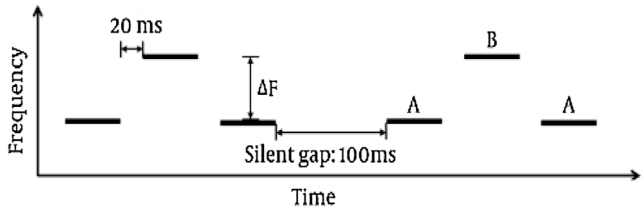

Fig. 1. Schematic representation of stimuli pattern to ASS measurement (ΔF: frequency difference between the pure tones A and B) [35].

The amplitude of A and B stimuli was considered equal. Their intensity level was also considered comparable owing to the effect of the increase in intensity on the FB value [33]; the stimuli were presented binaurally at the intensity of 40 dBSL to minimize the effect of the intensity level on the results of the study. The A tone frequency with the values of 500, 1000, and 2000 Hz was selected as the basis in the sequence of the presented triplets. The B tone was presented with the difference of 4–100% above the basis tone frequency. Each trail contains five triplets[35]. At the end of each trail, the individuals were asked whether they heard the presented sounds as a fluctuational rhythm or perceived them as two separate sounds (A–A. . . and B–B. . .). We instructed participants to raised the right hand if they heard the stimulus as a continuous sound and the left hand if they perceived it as two separate sounds.

A five-minute-long break was intended between in order to enhance the test validity. If the subject feels exhausted, the test was discontinued and deferred to the next day.

Herein FB was measured for each frequency independently. Thus, FB is considered the minimum frequency difference (ΔF) between A and B frequencies at which an individual can recognize the presented stimuli as two streams [15]. Then, the FB thresholds were calculated as difference between the number of equivalent rectangular bandwidths (ERBs) or ΔE using the following formula: $E = 21.4 \log(4.37F + 1)$ [33]. The scale E is a logarithmic scale of frequency for matching the internal representation of the sound [34]. When the difference between the center frequencies of consecutive tones in FB is expressed in terms of E, ΔE remains almost constant at different frequencies. The prediction is based on the fact that when ΔE has been fixed, the overlap between stimulation patterns of the two tones remains virtually unchanged.

Test stimuli were constructed using MATLAB10 [35]. Stimuli were played on a DVD player, and presented to participants through headphones. All sounds were calibrated before presentation.

2.3. Statistical analysis

Mean and standard deviation (SD) were obtained for all data. Repeated measure analyses of variance (RM-ANOVAs) were performed to compare FB thresholds in two groups at three tested frequencies. $P < 0.05$ was considered statistically significant.

3. Results

Herein, the FB thresholds were measured for sighted and early blindind ividuals in the frequency range 500, 1000, and 2000 Hz in terms of ΔE. Fig. 2 indicates that FB thresholds in the early

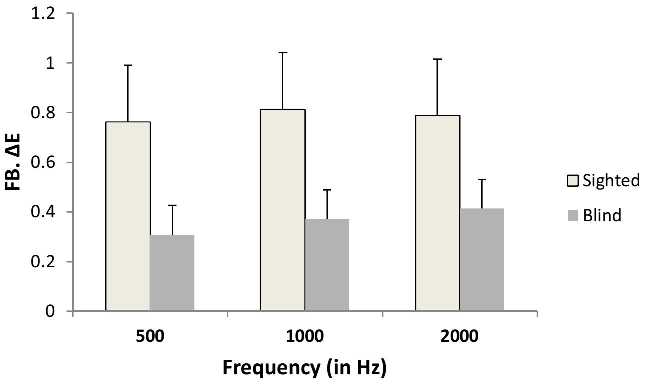

Fig. 2. FB thresholds in adult sighted and blind individuals at frequencies of 500, 1000, and 2000 Hz in terms of ΔE. The minimum frequency difference between A and B frequencies at which an individual can recognize the presented stimuli as two streams in the blind group was smaller than in sighted individuals ($P < 0.001$). Error bars indicate one standard deviation (SD).