ORIGINAL ARTICLE

Frequency Selectivity of the Auditory System in Females with Anemia: An Indian Scenario

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Abstract

Background: Frequency selectivity is one of the processes of the auditory system to evaluate the individual components of a complex sound. Frequency selectivity is one of the most critical factors that determine speech perception, particularly in the presence of competing signals. Anemia is a clinical scenario in which there is a decreased level of red blood cells. Evidence suggests that anemia is more prevalent in females than males and could be an early indicator of hearing loss. The objective of the study is to compare the frequency selective abilities in normal hearing females with and without anemia.

Materials and methods: A total of 30 females in the age range of 20–30 years with hearing sensitivity within normal limits participated, in which 15 females were anemic, and 15 females were non-anemic. A total of 60 ears were evaluated. The auditory system frequency selectivity was measured through psychophysical tuning curves (PTCs) at different characteristic frequencies (500, 1000, 2000, 3000, and 4000 Hz), and Q10 values for the same were calculated at different characteristic frequencies.

Results: In this study, there was reduced Q10 value for females with anemia at all the characteristic frequencies compared to females without anemia, indicating poor frequency resolution in females with anemia.

Conclusion: The outcomes of the present study will help in understanding the changing frequency selectivity of the auditory system in individuals with anemia.

Keywords: Anemia, Characteristic frequency, Frequency resolution, Frequency selectivity, Psychophysical tuning curves, Q10.

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Introduction

Frequency selectivity or frequency resolution is the capability of the auditory system to resolve the individual components of a complex sound. It represents one of the most critical functions of the auditory system by mediating both speech perception and the binaural localization of sound.[1] On the contrary, frequency resolution measures the auditory system's ability to encode the sound based on its spectral characteristics, such as detecting one frequency component in the presence of other frequency components in the stimulus. It has been more accurately described as the ability of the auditory system to isolate certain specific frequency components of a stimulus by filtering out other parameters in the stimulus.[2] What is more interesting to professionals in applied hearing science is that frequency selectivity is directly proportional to the auditory filter's bandwidth whose outputs stimulate the inner hair cells.[3] The usual method to design the frequency-selective behavior of the ear is to develop a series of overlapping bandpass filters, the auditory filters in which the bandwidth and shape are frequency and to some extent level dependent. The terms frequency selectivity, frequency resolution, and frequency analysis are often used to mean the same phenomenon.[4] It is the fundamental ability of the auditory system and helps in attending to signals in exceptional circumstances, like in noisy conditions or in appreciating musical melody. Thus, it helps to enhance the signal-to-noise ratio, codes a wide bandwidth signal into a set of narrow bandwidth signals, and in the perception of a complex stimulus. While the phenomenon of frequency selectivity is well understood, the measurement of it accurately among different individuals is not an easy task. Two individuals having the same thresholds of hearing does not mean that they have the same amount of frequency selectivity.

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The threshold level audibility of a specific signal can be increased as a result of another signal and it is commonly referred to as masking. Masking techniques such as psychophysical tuning curves (PTCs) estimate the fine auditory phenomenon and also measure the differences in the value precisely. Speech signal sensitivity not only depends on its own frequency and intensity but also relies on various competing signals. If they are relatively closer, the sound of one frequency is masked by another and the quantum of masking decreases if there is a difference in the frequencies. Previous reports show that the masking provides, an effective estimation of frequency selectivity and there is a marked difference in frequency estimation between basilar membrane and psychophysical estimates as compared to the masking methods.[1] For example, (physiological) neural-tuning curves present very similar characteristics as observed in estimates of (psychophysical) auditory tuning curves.[5,6]

Anemia is a pathological state in which there is a decreased RBC level and the incidence is higher in females as compared to males. Research suggests that iron deficiency anemia affects hearing health.[7–10] Shiu–Dong Chung et al.,[11] evaluated the correlation between anemia and sudden sensorineural hearing loss. The results of the study indicated that individuals with anemia are at higher risk of developing sudden sensorineural hearing loss.

Since there is no evidence of protocols to identify the frequency selectivity ability in anemic individuals/populations, this study would aid in selecting appropriate management methods based on an individual's frequency resolution abilities.

Materials and Methods

Participants

The experimental group consisted of 15 anemic females having hearing sensitivity within normal limits [mean age, 26.2 years; standard deviation (SD), 2.62] and the healthy control group consisted of 15 non-anemic females having hearing sensitivity within normal limits (mean age, 25.4 years; SD, 2.89). A total of 30 females in the age range of 20–30 years (mean age, 25.8 years; SD, 2.75) participated in the study. A total of 60 ears were evaluated.

Inclusion Criteria

Individuals with normal hearing thresholds [Pure Tone Average (PTA) ≤15 dB]. Patients with bilateral "A" type tympanogram with the presence of reflexes, and speech discrimination scores greater than 90% were included in the study.

Females in the age range of 20–30 years were also included in the study.

Exclusion Criteria

Individuals with a history of head injury, neurological ailment, middle ear infection, and/or noise exposure. Individuals taking iron supplements for anemia. Individuals with hearing loss (PTA >15 dB). Individuals with hemoglobin below 6.00 gm/dL. Females with and without anemia of any age-group apart from 20 to 30 years and males were excluded from the study.

Selection of Participants

All the participants/females in the age range of 20–30 years with and without anemia were tested in a sound-treated room built as per the American National Standards Institute (ANSI) (1991) standards for noise levels. Air conduction and bone conduction pure tones thresholds for the frequencies 250, 500, 1000, 2000, 3000, 4000, and 8000 Hz were determined using a calibrated clinical audiometer (Maico MA 53) by using the modified version of Hughson and Westlake procedure. Speech identification testing was done with a live voice presentation of phonetically balanced monosyllables at maximum comfortable levels. Immittance evaluation for the 226 Hz probe was carried out with a calibrated middle ear analyzer (Maico MI 34). Ipsilateral and contralateral acoustic reflex thresholds were measured at 500, 1000, 2000, and 4000 Hz (Maico MI 34). The participants were seated comfortably and instructed not to move or swallow during the procedure. The participants who had hearing thresholds within 15dBHL (decibel hearing level), speech identification scores above 90%, and "A" type tympanogram with acoustic reflexes present at 500, 1000, and 2000 Hz were selected as participants in the study.

Study Design

- Experimental group: Subject with a hemoglobin level between above 7.00 gm/dL and below 10.00 gm/dL and diagnosed as anemic by a practicing physician. The minimum duration of the anemic period was 6 months and not longer than 1 year as assessed from the first laboratory test report.
- Control group: Subject with blood hemoglobin levels more than 12.00 gm/dL in the test done in the last 6 months.

Procedure (Psychophysical Tests)

Psychophysical Tuning Curves

Frequency selectivity ability/frequency resolution of the auditory system was assessed at characteristic frequencies 500, 1000, 2000, 3000, and 4000. Furthermore, Q10 a measure of frequency selectivity was computed for each characteristic frequency by plotting the threshold of tone for each frequency when presented to the test subject mixed with each of 8 narrow band noise with differing in their center frequency. Clinical audiometer Maico MA 53 was used for measuring PTCs and with the help of tuning curves Q10 value was calculated.

Stimuli

The signal frequencies were sinusoidal pure tones of 500, 1000, 2000, 3000, and 4000 Hz presented at 20-dB sensational level (SL). The masker frequency stimuli were a group of narrowband noise with a bandwidth of 80 Hz and each one of them varying in their center frequency. The presentation of masker frequency was varied in steps of 100 Hz.

Procedure

All the participants were tested in a sound-treated room built as per ANSI (1991) standards for noise levels. The pure tone of a given signal frequency was presented at 20-dB SL through TDH 39 headphones and the masker [narrow-band noise (NBN)] was presented simultaneously to the ipsilateral ear. The narrow-band noise masker was presented starting from 0 dBHL and increased up to the level where it masked the pure tone signal. This level of NBN masker was noted. The test was continued as described here: Keeping the characteristic signal frequency and level constant, the frequency of NBN was varied in steps of 100 Hz, both above and below the characteristic frequency, and the level at which the NBN masker masks the characteristic frequency was noted at each center frequency step. The values obtained were plotted with the x-axis representing frequency and masker level on the y-axis. Plotting frequency on the x-axis and the masker level on the y-axis would give a PTC for the characteristic frequency tested. The frequencies of the NBN masker which corresponded to a 10-dB difference of masker level from the characteristic frequency, both above and below the characteristic frequency, were noted which is referred to as Q10 bandwidth. These values were used to calculate Q10 as follows:

$$Q10 = \frac{\text{Characteristic frequency (CF)}}{\text{Q10 Bandwidth}}$$

where Q10-value denotes the auditory filter's frequency selectivity of the auditory system.

Table 1: Mean Q10 for various frequencies at right ear and left ear in non-anemic controls

	Right ear Q10 values					*Left ear Q10 values*				
N = 15	*500 Hz*	*1 kHz*	*2 kHz*	*3 kHz*	*4kHz*	*500 Hz*	*1 kHz*	*2 kHz*	*3 kHz*	*4 kHz*
Mean	1.525	3.109	5.553	8.166	10.888	1.551	2.887	5.221	7.833	10.444
SD	0.338	0.665	0.809	1.144	1.524	0.187	0.428	0.584	0.879	1.172

Table 2: Mean Q10 values at various frequencies for both right ear and left ear in anemic patients

	Right ear Q10 values					*Left ear Q10 values*				
N = 15	*500 Hz*	*1 kHz*	*2 kHz*	*3 kHz*	*4 kHz*	*500 Hz*	*1 kHz*	*2 kHz*	*3 kHz*	*4 kHz*
Mean	1.133	2.266	4.533	6.4	8.533	1.166	2.333	4.533	6.7	8.533
SD	0.129	0.258	0.516	0.686	0.915	0.122	0.243	0.516	0.774	0.915

Table 3: Comparison of mean Q10 values at various frequencies among the right ear and left ear in non-anemic controls

	Right ear		*Left ear*		
N = 15	*Mean*	*SD*	*Mean*	*SD*	*p-value*
500 Hz	1.525	0.338	1.551	0.187	0.787
1000 Hz	3.109	0.665	2.887	0.428	0.363
2000 Hz	5.553	0.809	5.221	0.584	0.271
3000 Hz	8.166	1.144	7.833	0.879	0.334
4000 Hz	10.888	1.524	10.444	1.172	0.334

Paired *t*-test; $p < 0.05$ was considered as significant

Table 4: Comparison of mean Q10 values at various frequencies among the right ear and left ear in anemic patients

	Right ear		*Left ear*		
N = 15	*Mean*	*SD*	*Mean*	*SD*	*p-value*
500 Hz	1.133	0.129	1.166	0.122	0.499
1000 Hz	2.266	0.258	2.333	0.243	0.498
2000 Hz	4.533	0.516	4.533	0.516	1
3000 Hz	6.4	0.686	6.7	0.774	0.334
4000 Hz	8.533	0.915	8.533	0.915	1

Paired *t*-test; $p < 0.05$ was considered as significant

Data Analysis

Descriptive statistics was used to represent the means. Paired *t*-test was used to analyze the significance within groups. An Independent *t*-test was used to compare between anemic and non-anemic groups; $p < 0.05$ was considered as statistically significant.

Results

A total of 30 female participants with normal hearing were selected as subjects for the present study. Among them, 15 females were diagnosed with anemia and the other 15 females had their hemoglobin level within normal. A total of 60 ears were evaluated. All the participants underwent pure tone audiometry, speech audiometry, and immittance audiometry before being selected for the study. Individuals with a hearing threshold of below 15 dB (reference average hearing thresholds at 500, 1000, and 2000 Hz), with no middle ear infections, speech identification scores between 90 and 100% at 40-dB SL and "A" type tympanogram with acoustic reflexes present at 500, 1000, and 2000 Hz were included in the study. None of the participants had any history of ear infections, ototoxicity, or exposure to noise.

Frequency selectivity of the auditory system was measured through PTCs. Psychophysical tuning curves were used to assess the quality of filters. Furthermore, Q10 was calculated at different characteristic frequencies (500, 1000, 2000, 3000, and 4000 Hz).

The mean Q10 for different characteristic frequencies, and SDs, of the two groups—without anemia and with anemia are shown in Tables 1 and 2.

Paired *t*-test was administered between ears within group at different characteristic frequencies in both without anemia and with anemia groups (Tables 3 and 4).

In this study, among the subjects without anemia and with anemia at different characteristic frequencies (500 Hz; 1, 2, 3, and 4 kHz), the Q10 values between right vs left ear were found to be non-significant ($p > 0.05$).

Table 5: Comparison of Q10 values at various frequencies between non-anemic and anemic patients

	Non-anemic group		*Anemic group*			
N = 30	*Mean*	*SD*	*Mean*	*SD*	*p-value*	*t-value*
500 Hz	1.537	0.269	1.15	0.124	<0.00001	7.15
1000 Hz	2.998	0.561	2.3	0.249	<0.00001	6.22
2000 Hz	5.387	0.714	4.533	0.507	<0.00001	5.33
3000 Hz	8	1.017	6.55	0.735	<0.00001	6.32
4000 Hz	10.666	1.354	8.533	0.899	<0.00001	7.18

Independent *t*-test; $p < 0.05$ was considered as statistically significant

The results of the independent *t*-test as depicted in Table 5 show that there was a significant difference ($p < 0.005$) in Q10 values at different characteristic frequencies (500; 1, 2, 3, 4 kHz) between anemic and non-anemic subjects having normal hearing sensitivity in both the ears.

In this study, even though both anemic and non-anemic female groups of age range 20–30 years had hearing sensitivity within normal limits in both ears, there was a significant difference in PTC Q10 values between the groups suggesting poor frequency resolution/selectivity in individuals with anemia.

Discussion

Currently, the pathophysiology of anemia-mediated hearing loss is still obscure, but some relevant mechanisms have been reported. The intricate vasculature of the cochlear elicits oxygen and nutrients required for the stria vascularis of the cochlear duct to preserve the ionic composition of the endolymph and the endocochlear potential.[12] In the event of anemia, there exists a decreased oxygen level in the arterial blood supplying labyrinthine as a result of decreased hemoglobin concentration which leads to ischemic damage to the cochlea.

Earlier studies indicate that anemia is a marked risk factor for ischemic stroke and patients affected with vascular disease are at marked risk for developing acute sensorineural hearing loss.[11,13] Apart from tissue oxygen supply, iron participates in various biological functions such as neurotransmitter metabolism, DNA synthesis, and nerve myelination.[14,15]

The purpose of the present study was to examine the variations in the frequency resolution/frequency selectivity ability of the auditory system in normally hearing females with and without anemia in the age-group of 20–30 years. Frequency selectivity is one of the most important factors that influence the perception of speech, especially in the presence of competing signals.

Psychophysical measures of frequency selectivity mainly depend on a peripheral and central mechanisms combination, but in the case of individuals with hearing loss this active process is dysregulated in the cochlea. Frequency selectivity is provided as a first approximation by the variation in mass and stiffness of the basilar membrane. The outer hair cells' active process and their afferent and efferent innervation serve to sharpen the tuning around a frequency of interest by suppressing the spread of excitation of energy from neighboring frequencies. Because the active process is also responsible for the detection of low-intensity sounds, listeners with tone detection thresholds in the severe hearing loss range will necessarily have impaired frequency selectivity.[16] In this study, Q10 values at different characteristic frequencies (500 Hz; 1, 2, 3, and 4 kHz) between anemic and non-anemic subjects are found to be significant ($p < 0.05$). Similar to our report, in a study done by Verheij et al.[17] hearing loss and speech perception in noise abnormalities are common in Fanconi anemia.

Conclusion

Anemia in young females may affect the auditory system, specifically the inner ear–afferent fibers system in very subtle ways. Anemia may affect the fundamental auditory ability of frequency selectivity, an ability to differentiate two sounds differing in the frequency of a few hertz only. Anemia longer than 6 months seems to significantly affect the fine ability of our hearing system.

Further research is required to know whether this decreased ability reverses to normal levels if anemia is treated and if so, the duration required for such an improvement. Anemia can have a significant effect on the auditory system and affect an individual's ability to listen and comprehend conversations in the presence of background noise. And these changes are not usually reflected in routine testing of the auditory system like pure tone audiometry.

Clinical Significance

Hearing impairment and loss of auditory functions is one of the major morbidities in anemic patients. Mounting studies are published with regard to the association between anemia and hearing loss. Meanwhile, frequency selectivity of the auditory system is also impaired in anemic patients. So, it is highly imperative for the ENT and audiologist to approach the hearing loss in anemic patients in this aspect and proper management must be given to improve the quality of life in these patients.

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