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RESEARCH ARTICLE

Evaluation of auditory stream segregation in individuals with cochlear pathology and auditory neuropathy spectrum disorder

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Abstract

Background and Aim: The central auditory nervous system has the ability to perceptually group similar sounds and segregates different sounds called auditory stream segregation or auditory streaming or auditory scene analysis. Identification of a change in spectral profile when the amplitude of a component of complex tone is changed is referred to as Spectral profile analysis. It serves as an important cue in auditory stream segregation as the spectra of the sound source vary. The aim of the study was to assess auditory stream segregation in individuals with cochlear pathology (CP) and auditory neuropathy spectrum disorder.

Methods: In the present study, three groups of participants were included. Experimental groups included 21 ears in each group with cochlear hearing loss or auditory neuropathy spectrum disorders (ANSD) and control group with 21 ears with normal hearing. Profile analysis was assessed using "mlp" toolbox, which implements a maximum likelihood procedure in MATLAB. It was assessed at four frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) for all three groups.

Results: The results of the study indicate that the profile analysis threshold (at all four frequencies) was significantly poorer for individuals with CP or ANSD compared to the control group. Although, cochlear pathology group performed better than ANSD group.

Conclusion: This could be because of poor spectral and temporal processing due to loss of outer hair cells at the level of the basilar membrane in cochlear pathology patients and due to the demyelination of auditory neurons in individuals with ANSD.

Keywords: Auditory stream segregation; auditory scene analysis; spectral profiling; spectral profile analysis; cochlear pathology; auditory neuropathy spectrum disorders

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Introduction

Normal hearing listeners can identify the notes of a guitar in an orchestral piece effortlessly, or can easily attend to the nearby speaker even in a very noisy environment. Though the task looks easy it involves a great deal of complex processing at the level of the brain. It is a process in which sounds with similar characteristics are grouped together and those with differences are separated and is known as auditory stream segregation, or simply "auditory streaming" [1]. Several cues that help in grouping and segregating sounds play an important role in auditory stream segregation.

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Acoustic cues such as onset timing and spectral regularity of the successive sounds are grouped as a single stream. Along with acoustic cues (bottom-up cues), there are top-down cues such as attention expectations and stored internal templates or schemas play an important role in auditory stream segregation [2,3]. Spectral profiling is one of the vital cues which helps in auditory stream segregation.

Spectral profile analysis refers to the identification of a change in spectral profile when the amplitude of a component of a complex tone is changed. This change is heard as the change in timbre which can help to assess spectral profiling [4]. Thus, the profile analysis task can assess the sensitivity of the auditory system to variations in spectral shapes of the auditory stimuli.

There is enough evidence regarding the harmful effects of cochlear pathology (CP) and auditory neuropathy spectrum disorders (ANSD) on spectral and temporal processing of auditory stimuli. Several authors reported poor difference limen for frequencies (DLFs) in individuals with CP [5-13]. On few tests of temporal resolution, such as the detection of gaps in bands of noise or the rate of recovery from forward masking, cochlear hearing loss patients perform significantly worse than normal-hearing subjects when tested at the same sound pressure levels (SPLs) but near normal at equal sensation levels (SLs) [14-16]. Similarly, individuals with ANSD also showed poor performance on various psychoacoustic measures of spectral and temporal processing. The spectral resolution is acutely affected at low frequencies but normal at high frequencies, supporting the duplex encoding of the pitch using the phase-locking cue at low frequencies and the place cue at high frequencies. Temporal processing measures showed that individuals with ANSD have difficulty in detecting short sounds, but not long sounds, difficulty in gap detection even at comfortable loudness levels and have difficulty in detecting both slow and fast temporal modulations [17]. Another study revealed higher difference limen frequency (DLF), higher difference limen intensity (DLI), higher difference limen time (DLT), poor gap detection threshold (GDT), abnormal temporal integration function, and significant lower masking level difference (MLD) in individuals with ANSD [18].

Based on above-explored literature, spectral and temporal processing abilities are extremely deteriorated in individuals with cochlear hearing loss and ANSD, which may result in poor auditory stream segregation in them as well. There are no studies reported in the literature which have attempted to understand the effect of auditory streaming abilities in individuals with CP and ANSD. Thus, the present study aimed at assessing auditory stream segregation through spectral profile analysis tests in individuals with normal hearing sensitivity, CP, and ANSD at four different frequencies.

Methods

Participants

Three groups of participants were incorporated into the study. Two clinical groups were considered, i.e. one group with CP (Group A) and another group with ANSD (Group B). Control group comprised of individuals with normal hearing sensitivity.

Group A (cochlear pathology)

Twenty-one ears diagnosed with CP were selected randomly, between the age group of 15 and 45 years. The participants with a flat configuration symmetrical hearing loss with a pure tone average of more than 25 dB and less than 55 dB in both ears from 250 Hz to 4000 Hz were considered in the study. Otoacoustic emissions were absent in all the participants which confirmed the presence of cochlear pathology.

Group B (auditory neuropathy spectrum disorders)

Twenty-one ears diagnosed with ANSD aged between 15 to 45 years were included in the study.

All the participants were selected based on the clinical diagnostic criteria suggested by [19,20]. Otoacoustic emissions were present and auditory brainstem response was absent in all the participants which confirmed the presence of

retrocochlear pathology.

Control Group

Twenty-one ears with normal hearing sensitivity underwent the study following a random selection. The age group of the participants was 15–45 years. Individuals with pure tone average (PTA, an average of pure tone thresholds at 500, 1000, 2000, and 4000 Hz) [21] of less than or equal to 15 dB HL were considered in the study. All of them had A or As type tympanogram with the presence or absence of acoustic reflexes based on the degree of hearing loss (ipsilateral and contralateral) from 500 Hz to 4000 Hz. None of the participants had any history of conductive pathology symptoms. Those patients who were undergoing treatment for any neurologic disorders were excluded from the study.

Tests were done using non-invasive procedures, and all the participants were informed about the objectives and procedures of the study prior and informed consent was obtained from each of them.

Procedure

The Profile Analysis test in the MATLAB software [22] with the psychoacoustics toolbox was used to assess the individual's sensitivity to auditory stream segregation. A profile analysis test was conducted at four fundamental frequencies viz. 250, 500, 750 and 1000 Hz. A complex tone with five harmonics with the above mentioned fundamental frequencies was used. The presentation of different frequencies was randomized for all the participants in the study. In this experiment, the participant has to hear three complex tones. There are two identical tones with equal amplitude with the fundamental frequency of 330 Hz. The variable tone had exactly same harmonic structure but the amplitude of the third harmonic was increased in amplitude. The participant had to identify the tone with different timbre in a three alternate forced choice method. Each stimulus was of 300 ms duration and there was a time gap of 500 ms between each stimulus. The subject had to identify the odd timbre tone. The overall level of standards and the variable tone was varied randomly from trial to trial within a range of 5 dB. The onset and offset of tones were gated on and off with two 10-ms raised cosine ramps. The experiment was carried out as a 3-alternate forced-choice method. The profile analysis threshold was recorded in dB. The thresholds were calculated as the average of the last four reversals using maximum likelihood procedure. There were 30 trials for each frequency. All the stimuli were presented through personal computer routed through audiometer, equipped with tele dynamic headphones (TDH) 39 circum-aural headphones, at 70 dB HL. The complete testing was conducted in a sound-treated double room setup.

Compliance with ethical standards

In the present study, all the testing procedures were carried out on humans using non-invasive techniques, adhering to the guidelines of the Ethics Approval Committee of the institute (SH/AIISH/ERB/Diss/34/20-21). All the procedures were explained to the participants, and informed consent was taken from all the participants of the study. The authors declare no conflicts of interest.

Statistical analyses

The data was analyzed using Statistical Package for the Social Sciences (SPSS). Shapiro Wilk test of normality was performed to determine whether the data were normally distributed or not. The test scores of the profile analysis for individuals with CP, ANSD, and normal hearing sensitivity were statistically analyzed using Kruskal Wallis H test and Mann Whitney U tests.

Results

For all the groups, spectral profile analysis was assessed using the "mlp" toolbox, which implements a maximum likelihood procedure in MATLAB. The data obtained were analyzed using the SPSS software version 20.0.

The mean and standard deviation (SD) of profile analysis threshold in individuals with normal hearing, CP, and ANSD at various frequencies are shown in Fingers 1, 2, and 3, respectively. The results of descriptive statistics showed similar scores across the frequencies.

Table 1. **Results of Mann Whitney U test comparing profile analysis threshold between the individuals with cochlear pathology and auditory neuropathy spectrum disorder across frequencies**

Groups	250 Hz	500 Hz	750 Hz	1000 Hz
Normal v/s CP	z = −5.93	z = −5.89	z = −5.91	z = −5.43
	p < 0.003	p < 0.003	p < 0.003	p < 0.003
Normal v/s ANSD	z = −6.08	z = −6.06	z = −5.42	z = −6.26
	p < 0.002	p < 0.002	p < 0.003	p < 0.001
CP v/s ANSD	z = −2.97	z = −2.27	z = −2.30	z = −2.18
	p < 0.006	p < 0.007	p < 0.008	p < 0.009

CP; cochlear pathology, ANSD; auditory neuropathy spectrum disorder

Shapiro Wilk test of normality was done, and the results showed that data was not normally distributed ($p < 0.003$). Hence, non-parametric inferential statistics were administered. Friedman test was done to compare profile analysis threshold across the frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in all three groups (normal hearing, CP, and ANSD separately. The results of Friedman's tests showed that there was no significant difference ($p > 0.43$) across frequencies in all three groups.

Since the data was not normally distributed, non-parametric Kruskal Wallis H tests were done to compare the profile analysis threshold between all three groups for each frequency separately. The results of the Kruskal Wallis H test showed that there was a significant difference ($p < 0.002$) for all four frequencies.

Since there was a significant difference in the Kruskal Wallis H test, three Mann Whitney U tests were done to compare the profile analysis threshold between the two groups separately. The results of Mann Whitney U tests showed that profile analysis thresholds were significantly different for all three groups. The results of Mann Whitney U tests are shown in Table 1 and Fig. 1. The results indicated the scores were significantly poorer in ANSD group, and the best performance was obtained for individuals with normal hearing sensitivity.

Discussion

The results of the study showed that the profile analysis thresholds were poorer in both the clinical groups compared to individuals with normal hearing. Within the clinical group, the scores were poorer in individuals with ANSD compared to cochlear hearing loss. In addition, there was no significant difference across frequencies in all the three groups. Spectral profiling is one of the important spectral cues for analyzing an auditory scene. Failure to analyze an auditory scene efficiently can result in inadequate communication. Altered transmission of sound on the basilar membrane as a result of broadened auditory filters due to cochlear damage affects pitch and temporal perception adversely [23]. The asynchronous firing of neurons in auditory neuropathy spectrum disorders affects spectral and temporal processing resulting in poor speech perception [17].

Several authors studied various psychoacoustic measures of spectral and temporal properties in individuals with cochlear hearing loss and ANSD. They reported that individuals with cochlear hearing loss performed poorly than normal hearing participants. Similarly, individuals with ANSD performed extremely poorly than individuals with normal hearing. Such poor performance in individuals with cochlear pathology is attributed to poor transmission of sound at the

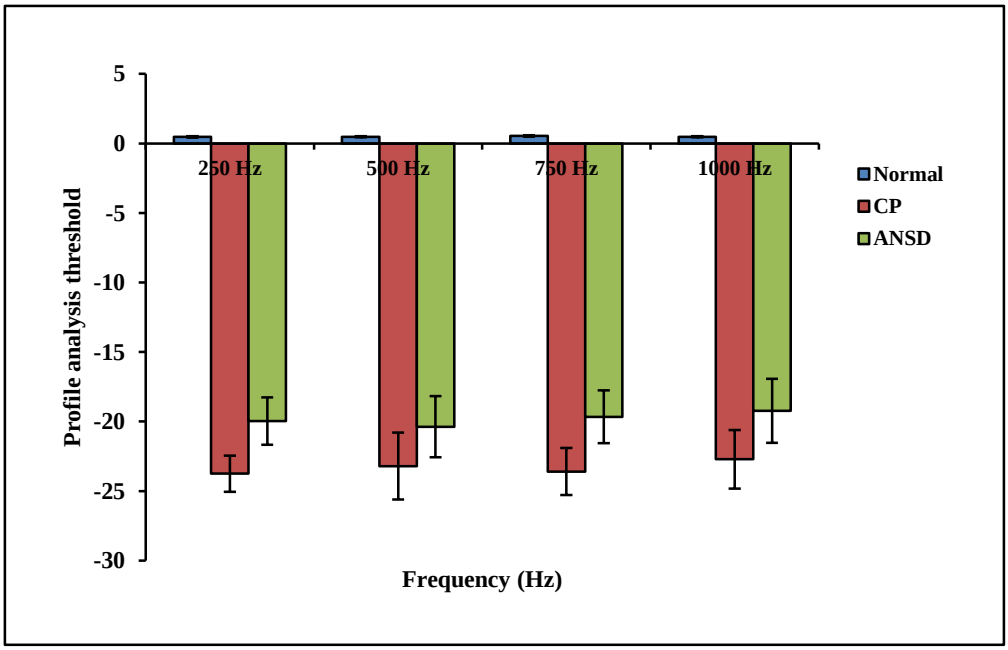

Fig. 1. Mean and standard deviation of profile analysis threshold across four frequencies in individuals with normal hearing, cochlear pathology and auditory neuropathy spectrum disorder. CP; cochlear pathology, ANSD; auditory neuropathy spectrum disorder.

basilar membrane and broadened auditory filters. On the other hand, loss of myelination of auditory neurons and disrupted auditory nerve function impacts spectral and temporal processing in individuals with ANSD [23,17]. Thus, the literature indicates that cochlear hearing loss and ANSD have profound effects on spectral and temporal processing of sound stimuli in the auditory system. The rationale for such findings is attributed to distorted transmission of signal at the basilar membrane and further impaired processing at the level of auditory neurons. When an auditory stimulus enters the cochlea, the signal is transmitted at the basilar membrane in accordance with the traveling wave theory [24]. Outer hair cells (OHCs) and inner hair cells (IHCs) define the elastic and stiffness properties of the basilar membrane in the cochlea. Loss of hair cells can result in impaired conveyance of signal at the level of the basilar membrane. Such damage is seen in cochlear hearing loss, where the loss of OHCs disrupts spectral and temporal processing of the auditory signal by the auditory nerve. After successful transmission of a signal from the basilar membrane to neuronal synaptic connections, the signal is processed by auditory neurons via synchronous firing as and when the signal arrives, which is further relayed to the central auditory nervous system. The asynchronous firing of auditory neurons due to degenerated myelin sheath is noticed in auditory neuropathy spectrum disorders resulting in poor spectral and temporal processing of auditory stimuli. Information carried by the central auditory nervous system is analyzed at the level of the auditory cortex via auditory stream segregation by using various spectral and temporal cues. Disrupted processing of spectral and temporal cues leads to impaired auditory scene analysis.

In the current study, results show poorer profile analysis threshold in individuals with cochlear hearing loss and ANSD than the normal hearing group. In addition, the cochlear pathology group performed better than ANSD group on the profile analysis task. The poor performance of the cochlear hearing loss group can be attributed to abnormal spectral processing of signals at the basilar membrane [15]. Such degradation in the signal

can result in inefficient processing of spectral cues at the level of the central auditory nervous system. This could have led to poorer performance on spectral profile analysis tasks in individuals with cochlear loss. The extremely poor performance of ANSD group can be imputed to the disrupted and asynchronous firing of auditory neurons, which makes it near to impossible to process spectral and temporal cues systematically by the central auditory nervous system. Although this is not the result of this study, it seems that spectral and temporal processing is an integral component of spectral profiling for auditory stream segregation, thus poor extraction of spectral cues due to damaged OHCs or demyelinated auditory neurons can be the cause of poor scores in this study [17]. However, the effect of cochlear pathology and auditory neuropathy spectrum disorders on auditory stream segregation can be further explored by studying other cues that are important for stream segregation.

Conclusion

The results of the present study demonstrated the adverse effects of cochlear hearing loss and auditory neuropathy spectrum disorder (ANSD) on spectral and temporal processing of auditory stimuli. Individuals with cochlear pathology performed poorly on spectral profile analysis tasks whereas individuals with ANSD performed worse. As spectral and temporal cues of an auditory signal majorly contribute to analyze an auditory scene effectively, it is concluded that cochlear pathology and ANSD affects auditory stream segregation drastically. Hence, further research is needed to study auditory stream segregation abilities in the clinical population.

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Conflict of interest

The authors declared no conflicts of interest.

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