EFFECT OF NUMBER OF CHANNELS IN HEARING AID ON SPECTRAL PROFILE ANALYSIS THRESHOLD IN INDIVIDUALS WITH HEARING IMPAIRMENT

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CERTIFICATE

This is to certify that this dissertation, entitled **“Effect of number of channels in hearing aid on spectral profile analysis threshold in individuals with hearing impairment”** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration number P01II21S0049. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **“Effect of number of channels in hearing aid on spectral profile analysis threshold in individuals with hearing impairment”** is the result of my own study under the guidance of Dr. N.Devi, Associate Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for award of any other Diploma or Degree.

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ABSTRACT

Auditory streaming, auditory stream segregation, or auditory scene analysis are terms used to describe the auditory system's ability to separate various sounds and group similar sounds. One of the important spectral cue that help in streaming is spectral profiling. Profile analysis tasks can be used to test how sensitive the auditory system is to the changes in spectral shapes. Spectral profile analysis thresholds are reported to be poorer in individuals with cochlear hearing loss and in the auditory neuropathy spectrum disorder(ANSD) group due to poorer spectral and temporal processing of incoming signals. Individuals decode various speech sounds using spectral information, altering the way hearing aids process the signal can improve the spectral processing in individuals with sensorineural hearing loss. The present study aims to assess and compare the spectral profile analysis threshold between 6,8 and 12-channel hearing aids across different frequencies (250 Hz, 500 Hz, 750 Hz, 1000 Hz) on individuals with mild – modetate sensorineural hearing loss. A total of twenty ears were included in the study. The spectral profile analysis threshold was assessed using the ‘mlp’ toolbox, which implemented the maximum likelihood procedure in MATLAB. The study results revealed no significant difference in the spectral profile analysis threshold between 6,8 and 12-channel hearing aids in all the test frequencies. Also, the spectral profile analysis threshold is better with a 1000 Hz test frequency compared to other frequencies. This might be due to the major harmonics of the test stimuli (1000 Hz) falling in the high-frequency region and the effectiveness of the number of channels in the same region.

Keywords: Stream segregation, Spectral profile analysis threshold, Multichannel amplification

CHAPTER 1

INTRODUCTION

The auditory system in humans is exposed to overlapping sources of acoustic information starting in infancy. Several auditory sources are active simultaneously in a typical listening environment. Only their combined spectra will be audible to the listener. In a complex auditory environment, the listener must separate the sounds and organize them into meaningful auditory objects or streams to selectively listen to one person's voice among others or to tune in a complicated musical arrangement (McDermott, 2009). This process is known as auditory scene analysis (ASA). The aim of auditory scene analysis, therefore, is to unravel the intricate puzzle of sound, ensuring that each sound source is perceptually distinct and recognizable. Two mechanisms are involved in auditory scene analysis. They are primitive grouping mechanism and scheme-governed mechanism. The schema-governed mechanisms are learned and influenced by the listener's specific experiences, the primitive grouping mechanism employs the fundamental physical qualities of the sound and may not require any individual experiences (Bregman, 1990).

Stream integration, coherence, or fusion are terms used to describe the process of grouping successive sounds into a single stream. However, the process is known as stream segregation, streaming, or fission if the succeeding sounds are separated and assigned to various streams (Noorden, 1975). When it comes to grouping sounds, two main methods can be utilized: sequential or simultaneous. In simultaneous grouping, the auditory system categorizes sounds based on their immediate succession in time.

Simultaneous cues provide instantaneous information and enable connections with concurrent auditory signalsn the sequential grouping of auditory signals, cues do not inherently contain any information and are only informative when compared with previous input (Bregman, 1990). These two methods provide different ways of organizing and perceiving sounds, and understanding their distinctions can greatly contribute to our understanding of auditory processes.

With its profound impact on our daily lives, scene analysis plays a pivotal role in understanding and interpreting auditory information. Through meticulous analysis of the acoustic characteristics of different sound sources, researchers and experts continue to unravel the fascinating intricacies of scene analysis, enhancing the knowledge and appreciation of this remarkable cognitive process. Behavioral studies have investigated the processing stages involved in auditory stream segregation. The peripheral channeling hypothesis is one of the influential theory suggests that early signal processing in the auditory periphery is the main foundation for streaming (Beauvois & Meddis, 1996). According to this theory, minimal overlap in the excitation pattern for different sound sources in the auditory peripheral structures (cochlea, auditory nerve) leads to stronger segregation. Acoustic cues based on peripheral coding, such as ear of stimulation and frequency range can lead to stream segregation. Another cue that helps in streaming is the overall intensity level of the sound sources, higher intensity leads to the broadening of the peripheral auditory filters, which in turn results in poor streaming (Rose & Moore, 2000). It doesn’t mean that because of the early processing happened in the periphery there is no further signal processing by the higher auditory structures. Studies have also shown that cues based on central coding, like amplitude modulation rate (Grimault et al., 2002), timbre (Cusack & Roberts, 2000), phase (Roberts et al., 2002), and bandwidth (Cusack & Roberts, 1999) can also contribute to stream segregation.

Various temporal, spectral, and combinations of both temporal and spectral cues help in auditory scene analysis (ASA). The major spectral cues that help in auditory scene analysis are spectral separation and spectral profiling, whereas temporal ordering, temporal separation, and temporal regularity are the important temporal cues (Yost & Sheft, 1993). Spectral profiling is one of the major spectral cue for stream segregation. The spectra of sound sources are clearly defined by the pattern of intensity variation as a function of frequency. Green and his colleagues (1983) have discussed listeners' ability to recognize variations in spectral form, a process known as “profile analysis”. Profile analysis tasks can be used to test how sensitive the auditory system is to the changes in spectral shapes (Green, 1983). Two complex sounds are typically presented in profile analysis experiments: a reference multi-tonal complex with equal amplitude logarithmic frequency-shaped sinusoidal components, and the signal where one component of the same multi-tonal complex contains an intensity increment (Green & Nguyen, 1988). The spectral form varies when one of the components is incremented . The detectability of this spectral shape change is measured during the task psychophysically.

Hearing loss leads to decreased audibility and a diminished capacity to "hear out" significant sounds in challenging acoustic environments (Moore, 2002; Oxenham, 2018). Damage to the inner ear hair cell or the auditory nerve causes sensorineural hearing loss. Pitch and temporal perception are negatively impacted by altered sound transmission on the basilar membrane caused by widened auditory filters in cochlear hearing loss (Moore, 1996). The spectral and temporal processing is affected in Auditory Neuropathy

Spectrum Disorders (ANSD) due to asynchronous neuronal firing (Zeng et al., 2005). The perception of timbre, which is mainly based on both the temporal and spectral components of sounds, is also affected by hearing loss. Changes in a sound's temporal envelope or long-term spectral structure may alter the perception of timbre. The spectral shape-related components of timbre perception depend on the ear's frequency selectivity, which is decreased in those with cochlear damage. Consequently, there is less information about the spectrum in the excitation pattern. As a result, one is less able to tell apart sounds based on their spectral structure (Van Summers & Leek, 1994). Additionally, suppression may affect how spectral form is internally represented, improving the contrast between peaks and valleys in the excitation pattern created by complex sound (Moore & Glasberg, 1983). Cochlear damage can result in loss of suppression which in turn affects the spectral form representation.

Research evidence shows that stream segregation is affected in individuals with cochlear damage (Bayat et al., 2013; Rose & Moore, 1997). For the formation of two auditory events, the two stimuli should excite separate neural populations (Beauvois & Meddis, 1996). Cochlear damage results in the broadening of auditory filters, which can lead to a greater degree of overlap of the excitation pattern in response to the auditory events, which leads to reduced stream segregation. Individuals with cochlear hearing loss have less capacity for stream segregation due to their wider auditory filters (Rose & Moore, 2005). Individuals with auditory neuropathy spectrum disorder also have poorer stream segregation due to the asynchronous firing of the auditory neuron making it impossible for the central auditory system to process the spectral and temporal information (Banerjee & Prabhu, 2021).

Amplifying sounds through hearing aids (HAs), can help people with hearing loss partially restore their auditory threshold, which is important for increasing their ability to recognize speech. The loss of sensitivity can be efficiently compensated for by amplification, but more complex signal processing is needed under challenging listening conditions (Kollmeier & Kiessling, 2016). The incoming signal is split into numerous frequency bands in multichannel hearing aids, and each signal travels through a distinct amplification channel. Each channel in multichannel compression has its own compression (Dillon, 2012). Compared to single-channel amplification, multichannel amplification offers perceptual benefits for speech perception, audibility for low-level sounds, and listening in noisy environments (Moore & Glasberg, 1986). Hearing aid users quickly adjust to spectral discrimination processing in hearing aids (An et al., 2022). Theoretically, a multichannel compression system can better handle the difference in hearing threshold and dynamic range at various frequency regions by giving varying gains across channels. When someone is listening to noise, more channels in hearing aids are helpful, and the outcome has been claimed to be predicted by slow and quick compression as well as the listener's cognitive ability. More channels in the hearing aid provide a better fit in various environments (Yund & Buckles, 1995). Essentially, more channels help the clinician to program the hearing aid more effectively. If the patient has sloping hearing loss, a multichannel hearing aid helps the clinician set the appropriate gain to each frequency separately, which helps to provide better listening comfort to the patient. Yunk and Buckles (1995) concluded that individuals with mild to moderately severe hearing impairment to discriminate speech in noise improved markedly as the number of channels increased from 4 to 8 and showed no change in 8 and 16-channel hearing aids. In a multichannel hearing aid, the gain can be increased more specifically across frequency, which helps to increase the audibility of low-level cues. Huebert and Brennan (2022) found that a sharper psychophysical tuning curve (PTC) was obtained in a 16-channel condition compared to 4 and 8-channel conditions. The authors also found that the psychophysical tuning curve obtained in the 16-channel condition is most similar to the PTC obtained in normal individuals. This study concluded that more channels in the hearing aid help to restore normal or near-normal auditory function in hearing-impaired individuals.

However, some studies showed the negative effect of more channels in the hearing aids (Bor et al., 2008; Plomp, 1988). This negative effect can be attributed to the channel interaction (Walker et al., 1984), spectral shape alteration (Bustamante & Braida, 1987), and channel summation effect (Kuk & Ludvigsen, 2003) that can occur in a multichannel hearing aid. Studies show no effect of the number of channels in the hearing aid (Crain & Yund, 1995; Keidser & Grant, 2001). The variation in the research design, stimulus, and compression parameters can be the reason for the mixed results.

With these backgrounds, there were no attempts to compare the effect of the number of channels in hearing aids on spectral profile analysis threshold in individuals with hearing impairment.

1.2 Need for the Study

Individuals with sensorineural hearing loss (SNHL) have difficulty understanding speech in a challenging listening environment, and the inability to process spectral and temporal cues can be one of the main reasons for the deficits. While there is ample literature demonstrating the impact of hearing loss on auditory stream segregation, there are comparatively few studies discussing the impact of hearing loss on spectral profiling.

However, no studies investigated the effect of amplification using hearing aids in auditory stream segregation. Hearing aids amplify the signal, but more sophisticated technology, such as multichannel amplification, can improve their stream segregation ability. Until now, there is no clear idea about the number of channels that better identify the change in the spectral shape. So, this study aims to find the effect of the number of channels in a hearing aid on spectral profile analysis threshold in hearing-impaired individuals. Since spectral profiling is one of the cues for auditory stream segregation, this study sheds light on how the number of channels affects auditory stream segregation.

1.3 Aim of the Study

- To assess and compare the effect of the number of channels in hearing aid on auditory stream segregation ability through spectral profile analysis test in individuals with mild to moderate sensorineural hearing loss.

1.4 Objectives of the Study

- To assess the spectral profile analysis thresholds in individuals with mild to moderate sensorineural hearing loss at different frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in
    - 6-channel hearing aid
    - 8-channel hearing aid
    - 12-channel hearing aid

- To compare the spectral profile analysis thresholds in individuals with mild to moderate sensorineural hearing loss at different frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in
    - 6-channel hearing aid
    - 8-channel hearing aid
    - 12-channel hearing aid
- To assess the effect of the number of channels in the hearing aid on auditory stream segregation ability through spectral profile analysis test in individuals with mild to moderate sensorineural hearing loss.
- To compare the effect of the number of channels in the hearing aid on auditory stream segregation ability through spectral profile analysis test in individuals with mild to moderate sensorineural hearing loss.

1.5 Null Hypotheses

- There is no significant difference in the spectral profile analysis thresholds at different frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in individuals with mild to moderate sensorineural hearing loss in 6-channel hearing aid.
- There is no significant difference in the spectral profile analysis thresholds at different frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in individuals with mild to moderate sensorineural hearing loss in 8- channel hearing aid.
- There is no significant difference in the spectral profile analysis thresholds at different frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in individuals with mild to moderate sensorineural hearing loss in 12-channel hearing aid.

- There is no significant difference in the spectral profile analysis thresholds across three different hearing aids with different channels (6, 8, and 12).

CHAPTER 2

REVIEW OF LITERATURE

2.1 Auditory Scene Analysis

Beginning in infancy, humans are exposed to a complex auditory environment of several concurrently active sound sources that frequently overlap in a wide range of acoustic properties. However, individuals perceive a coherent auditory environment of identifiable auditory events. Bregman (1990) coined the term "auditory scene analysis" (ASA) to describe this process of grouping and separating sensory data into distinct mental representations known as auditory streams. When sound enters the ear, the entire eardrum vibrates. Sound is separated into its frequency components by the inner ear. Each component must be assigned to the appropriate sound source somewhere in the auditory system. By the publication of an article by Bregman that introduced the auditory stream segregation paradigm (Bregman & Campbell, 1971) much of the research started to occur in this area. The authors of this study demonstrated that when pure tones were changed at sufficiently quick rates in two frequency ranges, low and high, participants heard two distinct streams of sound, one with low tones and the other with high tones. Instead, on a given trial, listeners first perceive one stream, and after a few seconds of accumulation, the two alternating tones separate into two streams. The development of two streams does not occur instantly following the presentation of two differing frequency tones in a subsequent presentation. The auditory scene analysis primarily uses the primitive grouping mechanism and the schema-governed mechanism (Bregman, 1990). An experiment in which two pure tones were aligned, and the individual was asked to perceive them makes it simple to understand how primitive grouping mechanisms work. If the frequencies of the pure tones were near enough together, the patient would perceive the signal as a single stream (van Noorden, 1977). For primitive grouping, the acoustic properties of the signal are enough to perceive the stream (Bregman, 1990). On the other hand, the schema-governed process is based on learned behaviors and requires some training, such as musical training (Bregman, 1990).

Combining successive sounds into a single stream is referred to as stream integration, coherence, or fusion (Noorden, 1975). If the successive sounds are divided and assigned to different streams, the process is known as stream segregation, streaming, or fission (Noorden, 1975). Sequential grouping and simultaneous grouping are both fundamental methods that can be used to organize sounds. According to their immediate sequence, sounds are grouped simultaneously by the auditory system. In addition to enabling linkages with concurrent auditory inputs, simultaneous cues offer immediate information. Cues do not carry any information by themselves when grouping auditory signals sequentially; rather, they only provide information when contrasted to prior input (Bregman, 1990).

A cognitive model of streaming which was proposed by (Bregman, 1990) is based mainly on Gestalt concepts like common fate (two or more complex sound components that undergo the same kind of changes at the same time are grouped and perceived as coming from the same source), proximity (sounds are grouped based on proximity), similarity (the sound elements will be grouped if they have similar pitch, timber, loudness, or subjective location), and good continuation (this exploits a physical property of sound sources that changes in frequency, intensity, and location or spectrum tends to be smooth and continues rather than abrupt, smooth changes in any of this aspect indicate a change in a single source, whereas sudden changes indicate that a new source has been activated). It is believed that streaming is a multistage process, in which an early, preattentive phase divides the sensory input and causes successive sounds to be associated based on the relationship between pitch proximity and presentation rate.

The physiological basis of auditory scene analysis is extensively studied. It has been suggested that cochlear filtering plays a major role in auditory streaming. According to the peripheral channeling hypothesis, which has gained much popularity, streaming mainly occurs due to peripheral signal processing (Beauvois & Meddis, 1996). According to the Beauvois and Meddis computer model, streaming depends on how much successive sounds' excitation patterns overlap; a large level of overlap results in fusion, while a low level of overlap results in fission (Beauvois & Meddis, 1996). This high degree of overlap provides higher levels of the nervous system with clear evidence for clearly distinguishable sound sources.

Hartmann and Johnson (1991) evaluated the efficacy of different acoustic dimensions in streaming. Finding pairs of well-known melodies that were mixed was the task. The notes of the two melodies could differ in one of several characteristics. The aim was to identify pairings of well-known tunes that have been combined. The two melodies' notes could be different in one or more ways. The most effective cues for segregation in this investigation were ear stimulation, melody frequency range, and spectrum (pure tone vs. harmonic complex) cues based on peripheral coding (i.e., different stimulation of the right and left ears or tonotopy). These were the most effective cues for segregation. The overall intensity level is another cue that affects streaming, with higher overall intensity resulting in a drop in streaming judgments for alternating low and high tones (Rose &

Moore, 2000). As the intensity increases, a larger area in the basilar membrane gets activated, leading to the overlap of the excitation pattern evoked by the two tones.

However, studies have also shown that cues based on central coding, like amplitude modulation rate (Grimault et al., 2002), timbre (Cusack & Roberts, 2000), phase (Roberts et al., 2002), and bandwidth (Cusack & Roberts, 1999) can also contribute to stream segregation in the absence of peripheral cues. Furthermore, there is general agreement that processing and perception of auditory objects are mediated by the ventral auditory pathway, a network of brain areas that comprises the core auditory cortex, the anterolateral belt region of the auditory cortex, and the ventrolateral prefrontal cortex (Rauschecker & Tian, 2000).

However, recent research indicates that fission can happen even for sounds with extremely similar, or even identical, power spectra, which would result in comparable excitation patterns (Moore, 2002). In normal hearing, these processes have been studied in experiments that used sequences of repeating, sequentially presented sounds. These stimuli differ in acoustic characteristics, such as frequency content (Noorden, 1975) or temporal envelop (Cusack & Roberts, 2000).

2.2 Spectral Cues for Auditory Stream Segregation

Various temporal, spectral, and combinations of both temporal and spectral cues help in auditory scene analysis (ASA). The major spectral cues that help in auditory scene analysis are spectral separation and spectral profiling, whereas temporal ordering, temporal separation, and temporal regularity are the important temporal cues (Yost & Sheft, 1993). The spectral cues in the acoustic stimuli are frequency-related, while the temporal cues are time variations in the sound stimulus. The basilar membrane detects two separate streams when two alternating pure tones stimulate two separate locations in the membrane (Beauvois & Meddis, 1996). So if the frequency difference between the two signal are greater, then it will lead to fission and if the difference is small, fusion will take place (van Noorden, 1977).

One of the key spectral cues for stream segregation is also thought to be the stimulus bandwidth. In a noise burst, the effects of bandwidths and the center frequency on stream segregation were investigated by Bregman and his colleagues (2001). Authors alternated between bursts of filtered band-pass noise that had sharp band edges. Subjects with normal hearing sensitivity were asked to determine whether they perceived the sequences as one or two streams. Broader noise burst bandwidths were shown to significantly impact stream segregation. They concluded that the cochlea's excitation pattern significantly impacts the separation of the auditory streams.

The separation of auditory streams was also shown to be influenced by the fundamental frequency (F0) and its harmonics. Pitch and timbre were used by Singh (1987) to examine how the brain perceives alternating complex tone stimuli. Changes in the F0 provided pitch cues, and timbre cues in the complex tone were provided by variations in the harmonics. A sequence was delivered, and listeners with typical hearing sensitivity were asked to determine whether it included one stream or numerous streams. In contrast to pitch variations, he discovered that timbre differences between complex tones have a much larger role in the development of streams. Variation in the harmonics of the stimuli forms stronger stream segregation in individuals with normal hearing sensitivity (Houtsma & Smurzynski, 1990). To conclude, the stream segregation scores improved when the complex tones were higher. This might be due to the larger difference in the excitation pattern elicited by the higher harmonics.

2.3 Auditory Spectral Profiling

The pattern of intensity variation as a function of frequency is what defines the spectra of sound sources. These patterns are often relatively invariant across changes in the source output level, so source determination requires the ability to process the spectral pattern or profile of the source output independent of the overall level. Green and his colleagues (1983) have discussed listeners' ability to recognize variations in spectral form, a process known as “profile analysis”. The sensitivity of the auditory system to detect changes in spectral shapes can be assessed using profile analysis tasks (Green, 1983). The change in the spectral shape can made by adding an increment to one component of the signal, and this change in the spectral shape produces a qualitative difference in the sound, which can be stated as timber perception. The scale of timber ranges from simple descriptions to multidimensional scales, but sound with different spectra often has different timber (Hirsh, 1988). So, the spectral profile is the stimulus variable most responsible for timber. Listeners' ability to process differences in timber is crucial to distinguish one sound source from another.

When there are few components (a low density of spectral components in the complex), the ability to identify the increment in the intensity is poor. As the number of components is raised, the ability increases, but it becomes poorer again as the density of components is increased further (Green, 1993). The experiment done by Green (1993) found that the intensity increment was easier to detect in an 11-tone complex than in a 3-tone, 41-tone complex. The spectral peak is less evident when the component density is higher and when the components are few and widely spaced. The components overlap within a single auditory channel or critical band when the density is too high, masking the increment.

Bernstein and Green (1987) investigated the sensitivity of a single group of listeners to a wide variety of simple and complex spectral changes. The authors used logarithmic frequency-spaced multi-tonal complexes with component numbers ranging from 3 to 81; the lower frequency (200 Hz) and upper frequency (5000 Hz) were kept constant. The authors found that the threshold improved as the number of components from 3 to 21, and beyond 21 components, thresholds increased monotonically. From this data, the resolution bandwidth was estimated around 160 Hz for a central frequency of 1000 Hz. Another study by Zera et al (1993) examined the profile analysis of harmonic signals. The authors estimated the width of the resolution band to be around 1.66 equivalent rectangular bandwidth (ERB). The results of these studies reveal that the width of the frequency channels in a profile analysis task is generally considered to be either the same as or slightly larger than the width of the critical band.

Goyal (2020), studied the effect of age and gender on auditory stream segregation abilities in individuals with normal hearing through a spectral profiling task. The study used a cross-sectional design in which participants were selected randomly. Group A comprised participants aged 21 to 30; Group B, 31 to 40; and Group C, 41 to 50. There were 40 individuals in each group, with 20 men and 20 women. The spectral profiling task was measured using the ‘mlp’ toolbox, which uses the maximum likelihood procedure in MATLAB. The test was conducted in four frequencies, 250Hz, 500Hz,750 Hz, 1000Hz. The result shows that Group A performed better compared to the other two groups. The better performance in the younger group is attributed to the changes in the neural structures. With aging, there is a decrease in the attention span, and working memory as well as changes in neural structures and physiology. As age increases there is a decline in tonic inhibition which increases the neural noise, which also affects the central auditory process as well. A decrease in neural functioning reduces the stream segregation ability. The authors found no significant gender effect in the study, but males performed slightly better than females. Due to menstruation and pregnancy, females have increased estrogen and progesterone levels. These hormones affect the psychoacoustic test in females (Sao & Jain, 2016). This can be the possible reason for the present study findings. This study concluded that there is an age effect in spectral profiling, but there is no significant gender effect.

Johnson and her colleagues (2021) studied the spectral profile threshold in individuals with and without music training. Forty participants with normal hearing sensitivity within the age range between 18 and 30 years old (mean: 24.5; standard deviation (SD) = 3.2) were included in the study. Participants were divided into 2 groups. Group 1 consisted of 20 musicians (> 1 year of musical training) and Group 2 consisted of 20 non musicians (no formal and informal music training). The test was done using MATLAB software using the psychoacoustic toolbox. Spectral profile analysis threshold was obtained for 330Hz. The stimulus was presented through a personal computer with supra-aural headphones at 60 dBHL. This study showed that there is a significant difference in spectral profile analysis threshold between the musician and no musician group. Also, it was found that there is a positive correlation between years of musical training and the spectral profile threshold. Authors proposed that improved attention and enhanced spectral processing can be the reason for better spectral profile threshold in musicians.

Spectrotemporal cues that help identify and discriminate are better perceived by an individual who underwent musical training (Micheyl et al., 2006). In an adverse listening situation, musicians better extract speech cues (Bidelman & Krishnan, 2010). Studies showed that musicians have narrow auditory filters (Soderquist, 1970), also they perceive the changes in spectral timber can be because of their sharper tuning curves (Amos & Humes, 2007). Attention plays an important role in stream segregation, the stream segregation ability changes as a distractor noise is presented along with the stimulus. When the subject is asked to ignore the distractor the scores become better (Carlyon et al., 2001).

2.4 Effect of Hearing Loss in Auditory Stream Segregation

Around 15% of adults worldwide were expected to have some degree of hearing loss (HL) in 2012, according to estimates from the World Health Organization (WHO), which put the number at 360 million, or 5.3% of the world's population (Olusany et al., 2014). Sensorineural hearing loss is characterized by damage to the sensitive hair cells in the inner ear or damage to the auditory nerve. People with hearing loss have difficulty understanding speech in situations involving stream segregation, such as when there is background noise, compared to people with normal hearing. The reduced ability for stream segregation may be the cause of this.

Bayat and colleagues (2013) compare the auditory scene analysis ability in individuals with normal hearing and hearing-impaired. A total of 40 participants were included in the study. The participants were divided into two groups, the control, and the experimental (mild-moderate sensorineural hearing loss) group. The authors used an ABA-ABA sequence for assessing auditory scene analysis ability. The "A" tone's frequency was fixed at 500, 1000, 2000, or 4000 Hz, while the "B" tone's frequency ranged from 3 to 80 percent above the "A" tone. The frequency of the B stimulus was reduced for ASA threshold detection until respondents reported being unable to distinguish between two sounds. Results showed that the SNHL group performed poorer in all the frequencies than the normal group and the larger difference was seen in high frequencies. Sensorineural hearing loss can lead to broadening of the auditory filter thereby reducing the frequency selectively. Broadening of the auditory filter result in broadening of the excitation pattern as well, which lead to poorer auditory scene analysis ability. The decreased ability in the high frequencies can be due to the poorer frequency selectivity.

However, the evidence also implies that there is no discernible difference in stream perceptions between people with normal hearing and those who have cochlear hearing loss whenever there is a change in the temporal properties of subsequent sounds. In addition, numerous research on the perception of streams by people with sensorineural hearing loss that relied on either spectral or temporal signals are inconclusive (Dolležal et al., 2012)

Antony and Barman (2021) investigated the auditory stream segregation ability in individuals with sensorineural hearing loss (SNHL) with sinusoidal amplitude-modulated tonal stimuli. There were 30 normal-hearing individuals with a mean age of 27.4 years and 30 individuals with sensorineural hearing loss (mean age of 34.6 years). Two experiments were carried out in this study. In the first experiment, an AB series of sinusoidally amplitude-modulated stimuli (SAM) stimuli was presented, with the A stimuli having a reference or standard modulation frequency and the B stimuli having a target or comparison modulation frequency. Only a B stimulus sequence was shown in Experiment II. The experiment used both a low carrier frequency of 1 kHz and a high carrier frequency of 4 kHz. A lower standard modulation frequency of 16 Hz and a higher standard modulation frequency of 256 Hz were considered. The comparison modulation frequencies were 1 to 4 octaves higher than the typical modulation frequency. Picking up the irregularity in the rhythmic sequence when various levels of temporal delays were imposed was the objective listening task, and this delay was employed as a measure of stream perception. Regardless of the carrier frequencies, this study demonstrated that the capacity to identify irregularities when higher standard modulation frequencies were utilized varied significantly between the normal hearing group and the SNHL group. The SNHL group demonstrated worse stream perception because they could not distinguish the irregularities more well than the normal hearing group. The authors concluded that one of the reasons for the lower stream perception with sinusoidal amplitude-modulated tone stimuli in the SNHL group may be poorer frequency resolution.

2.5 Effect of Hearing Loss in Auditory Spectral Profiling

There are limited studies that investigated the effect of hearing loss on the spectral profiling ability of hearing-impaired individuals using psychoacoustic testing.

Banerjee and Prabhu (2021a) investigated the auditory stream segregation abilities in individuals with cochlear pathology and auditory neuropathy spectrum disorder using spectral profiling. Two clinical groups were included in the study: Group A: Individuals diagnosed with cochlear pathology (n=15, age range: 15-45 years). Group

B: Individuals diagnosed with auditory neuropathy spectrum disorder (n=15, age range: 15-45 years) and the control group with the same number and age of participants as that of the clinical group. The spectral profile threshold was obtained in 250Hz, 500Hz,750 Hz, 1000Hz. The result of the study showed that poorer spectral profile threshold in individuals with ANSD and cochlear pathology than in normal hearing. There is no difference between the three groups when comparing the spectral profile analysis threshold across four frequencies. Within the two clinical groups, the ANSD group had a poorer spectral profile analysis threshold than the cochlear pathology group. Abnormal spectral processing at the basilar membrane can be one of the reasons for the poor spectral profile analysis threshold in individuals with cochlear pathology. Extremely poor performance in the ANSD group can be attributed to the disrupted and asynchronous firing of the auditory nerve, which leads to poor processing of spectral and temporal processing of information by the central auditory system. The authors proposed that spectral and temporal processing is integral to spectral profiling.

2.6 Studies on the Effect of the Number of Channels in the Hearing Aid

Wide dynamic range compression (WDRC) is incorporated into the hearing aids to give level-dependent amplification and acceptable loudness (Souza, 2002). Theoretically, a multichannel compression system can better handle the difference in hearing threshold and dynamic range at various frequency regions by giving varying gains across channels. A majority of currently offered hearing aid models include two to one twenty-four compression channels, and the price of the hearing aids varies depending on the number of channels and functions offered. When someone is listening to noise, more channels in hearing aids are helpful, and the outcome has been claimed to be predicted by slow and quick compression as well as the listener's cognitive ability. Over the past 40 years, there have been many investigations done on multichannel compression systems. Still, the literature in this field is muddled by a large variety of factors such as variations in research design, test material, and the compression behavior itself.

Yund and Buckles (1995) published one of the most important behavioral investigations on the effect of the number of channels in the hearing aid. The authors investigated the effect of multichannel hearing aids on speech discrimination in noise. Sixteen individuals with mild-moderate hearing loss were taken as participants in the study. The authors used a closed-set nonsense syllable test as the stimuli, and the signal-to-noise ratio varied from -5 to -15 dB using speech spectrum noise, and they used two voices, one male and one female. The authors found that as the number of channels increased from 4 to 8, the speech discrimination score increased after there was no evident change in the scores when the number of channels increased from 8 to 12. This study shows that 8-channel hearing aid is needed to benefit fully from the multichannel channel compression. The positive effect of multichannel compression are it can provide a better fit with individuals with hearing impairment because the threshold elevation, recruitment, and loudness discomfit level varies with frequency. Multichannel compression hearing aids can amplify the signal frequency contents separately because each frequency content falls in separate channels. The detailed analysis of this study data failed to explain the negative effect of the increased number of channels.

Jyoti and Singh (2001) investigated the effect of the number of channels of hearing aids on speech perception in different degrees of sloping hearing loss cases. Thirty individuals with mild – severe sensorineural hearing loss in the age range of 18-55 years participated in the study. The subjects were divided into three groups based on the audiogram configuration. Group 1 had 10 participants with flat loss, Group 2 with moderately sloping, and Group 3 with steeply sloping hearing loss. Three hearing aids that differ only in the number of channels were used. Hearing aids were programmed using the NAL-NL1 prescriptive formula. Speech identification scores using a phonetically balanced (PB) word list in the Kannada language were obtained using 2,4, and 8-channel hearing aids. Also, the recorded version of the high-frequency Kannada speech identification test (HF-KST) was done. The intensity of the presentation was 40 dBHL. The authors found that speech identification scores for PB word lists improved with the increase in the number of channels in the hearing aid in all three groups. The authors proposed that the improvement might be due to the appropriate audibility given by each channel depending on the configuration of hearing loss. Speech identification score with high-frequency word list showed no improvement in the scores when the number of channels increased from 2- 4 but showed a significant improvement with 8 channel hearing aid. This could be due to the number of channels available for processing the signal after 1000 Hz.

Huebert and Brennan (2022) investigated the effects of hearing aid amplification on the perception of spectral cues. The study was done in thirty-seven individuals with sensorineural hearing loss (mean age = 69.9, standard deviation = 3.8) and eleven normal hearing individuals (mean age = 65.6, standard deviation = 6.8). Pure tone averages (PTA) of 1, 2, and 4 kHz between 35 and 65 dB HL, the threshold at 2 kHz 35 dB HL, the absence of an air-bone gap, and normal tympanometric results were the inclusion criteria of the sensorineural hearing loss group. Thresholds of 25 dB HL from 250 to

8000 Hz were required for the NH group. Stimuli was a 2-kHz (500-ms duration) pure-tone target presented at 10 dB sensation level (SL) and a .32-kHz wide masker (700-ms duration) in which the center frequency varied from 1 to 3 kHz in 10-Hz steps. Stimuli were amplified using the hearing aid simulator detailed in Brennan et al. (2015). The simulator utilized a filter bank, wide dynamic range compression, and output compression to produce hearing aid prescriptions in which the number of compression channels (4, 8, or 16) could be manipulated (Brennan et al., 2018). Each individual psychophysical tuning curve (PTC) was collected with a target frequency of 2 kHz, and the signal was presented as 10 dB SL in reference to a threshold obtained in quiet conditions. Obtained data were compared to the PTC obtained from normal-hearing individuals. The authors found that the 16-channel condition produces sharper PTC than the other two conditions. With the use of 16 channels in compression programming, clinicians can provide more personalized prescriptions that improve audibility for their patients across all frequencies and can restore more of the patient's normal function.

There are contradictory statements about the usefulness of multichannel hearing aids. Multichannel hearing aids should apply varying compression ratios to various channels based on the degree of hearing loss present at each frequency. This would lessen spectral contrast and alter the spectral shape of speech, lowering speech recognition scores (Plomp, 1988). Individuals with sensorineural hearing loss have greater difficulty in identifying the changes in the spectral shape of the signal (Leek et al., 1987). By the use of multichannel wide dynamic range compression (WDRC), there will be an additional reduction in the spectral contrast, which reduces the ability to perceive vowels, nasals, and semivowels whose phonemic cues are mainly identified by the change in the spectral shape (Franck et al., 1999). This negative effect can be attributed to the channel interaction (Walker et al., 1984), spectral shape alteration (Bustamante & Braida, 1987), and channel summation effect (Kuk & Ludvigsen, 2003) that can occur in a multichannel hearing aid.

Crain and Yund (1995) investigated the effect of multichannel compression on the discrimination of vowels and voiced stop consonants. For the vowel discrimination, four normal hearing individuals and nine individuals with sensorineural hearing loss with varying severity participated in the study. The KLSYN88a Laboratory Speech Synthesizer (M.I.T. and Sensimetrics Corporation) was used to create a set of vowel stimuli. With an update interval of 5 msec and a sample rate of 20 kHz, steady-state vowels lasting 500 msec were created using the cascade synthesis method. The set of stimuli included 10 vowels for each of the three voices (male, female, and child). Signal processing is done using two methods: 1) FLAT MCC (Multichannel compression), where each channel has the same compression ratio, and 2) SHAPED MCC, where each channel's compression ratio is tailored to the subject's particular auditory region. The stimulus was processed utilizing 2, 4, 8, 16, and 31 separate compression channels. As control conditions, unprocessed, linearly amplified stimuli were used. The stimuli were presented at the most comfortable level for normal individuals and individuals with hearing impairment. The authors found that in the FLAT MCC, there is a negative effect of high compression ratio and number of channels. Still, in SHAPED MCC there is no effect of the number of channels in the vowel discrimination score. Similar results were obtained in the voiced stop consonant experiment. This study concluded the negative effect of MCC processing occurs in extreme MCC conditions. In the case of FLAT MCC each channel has a similar compression ratio, so an equal amount of amplification is given to each frequency channel. Still, most individuals have more high-frequency hearing loss and less low-frequency hearing, giving equal amplification in both regions can lead to an upward spread of masking which might be the cause of the reduced score in the study. In SHAPED MCC the compression ratio depends on the hearing impairment at that particular frequency which reduces the over-amplification of low frequencies and eliminates the possibility of upward spreading of masking.

George (2012) investigated the effect of hearing aid channels on acoustic change complex (ACC). The participants of the study were 16 normal individuals(Control group) and 10 individuals with cochlear hearing loss(Experimental group) with a sloping configuration in the age range of 25-59 years. The stimuli used to record the ACC was /si/ with a duration of 250 msec, presenting in an alternating polarity at 65 dB SPL through a loudspeaker. Hearing aids were programmed using the NAL-NL1 prescriptive formula. Hearing aid target gain was matched correctly using real ear measurements.ACC was recorded with 2,4 and 8-channel hearing aids. The author found there is no significant effect of the number of channels in the hearing aid on the amplitude and latency of ACC. This might be due to the ceiling effect of aided response at high intensities due to the activation of the compression circuit in all the hearing aids (Korczak et al., 2005).

CHAPTER 3

METHOD

3.1 Research Design

The study implemented a within-group comparison. The selection of participants was based on a purposive sampling technique.

3.2 Participants

A total of twenty ears with mild-moderate sensorineural hearing loss were included in the study. The age range of participants was 18-40 years (mean years = 32.2, SD = 7.9).

3.2.1 Inclusion Criteria of the Participants

- Participants with bilateral mild–moderate sensorineural hearing loss with pure tone average ranging from >25 dBHL to ≤ 55 dBHL in air conduction for the octave frequencies from 250 Hz to 8000 Hz and bone conduction threshold from 250 Hz to 4000 Hz (ANSI S3.1-1999) and the air-bone gap of ≤ 10 dBHL.
- Participants with first-time hearing aid users (with no prior experience of use of hearing aid).
- Normal middle ear functioning was confirmed with a type A tympanogram with an acoustic reflex threshold appropriate for the degree of hearing loss.
- Unaided speech recognition scores ≥ 60% at 40 dB SL.
- Participant with the post-lingual onset of hearing loss.

3.2.2 Exclusion criteria of the participants

- Participants with chronic otitis media, retrocochlear lesions, endolymphatic hydrops, or hearing loss with a conductive or surgically correctible component.
- Participants with cognitive dysfunction or a history of cerebral accident.

- Hearing aid users were excluded from this study.

3.3 Test environment

- All the audiological tests were done in a sound-treated audiometric room with the background permissible noise level as per ANSI/ASA S3.1-1999 (R2018) standards. The testing room was free of distractions and had optimum temperature and lighting. All tests were done non-invasively. Before the study, all participants were informed about the procedures and objectives of the study, and written consent were taken from the participants for their willingness to participate in the study.

3.4 Instrumentation

- A calibrated dual-channel audiometer GSI 61 with TDH-39 headphones, housed in MX-41/AR (Telephonics, Farmingdale, NY, USA) ear cushions, were used to track the pure tone audiometry thresholds and administer speech audiometry among all participants. Radio ear B71 bone transducer (Radio ear, KIMMETRICS, Smithsburg, Maryland, USA) headset was used to estimate the threshold for bone conduction.
- The middle ear analyzer Gradson- Stadler Incorporated (GSI) Tympstar (GSI VIASYS Healthcare, WI, USA) was utilized to measure each participant's auditory reflex threshold, equivalent ear canal volume, peak static admittance, and tympanometric peak pressure.
- NOAH (version 4.6) hearing aid-specific module and NOAH link wireless were used to program the hearing aid.

- Three digital behind-the-ear (BTE) hearing aid models with six, eight, and twelve channels suitable for individuals with mild to moderate hearing loss were selected. The hearing aid had the provision of gained manipulation for three different inputs. The hearing aids were selected from the same manufacturer and the same family.
- Hearing aid fitment was verified using Aurical free fit (Otometrics, Denmark).
- A calibrated two-channel audiometer with a sound field was used to route the test stimuli from a computer (PC) installed with MATLAB software.

3.5 Procedure

3.5.1 Case history

The case history was taken in detail from all the participants to rule out any pathological conditions of the auditory system and associated medical or neurological history.

3.5.2 Otoscopic evaluation

An otoscopy was performed to see the tympanic membrane characteristics and exclude the presence of signs such as ear discharge, tympanosclerosis, impacted wax, etc.

3.5.3 Pure tone Audiometry

Using a modified version of the Hughson and Westlake procedure (Carhart &Jerger, 1959), pure tone audiometry was performed at octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction for all the participants.

3.5.4 Speech audiometry

Paired words in Kannada developed at the Department of Audiology, AIISH, Mysore was used to measure speech recognition threshold (SRT). Speech identification scores (SIS) obtained using phonetically balanced (PB) words in Kannada developed at the Department of Audiology, AIISH, Mysore.

3.5.5 Immittance audiometry

Tympanogram was recorded using 226 Hz probe tone in both ears, and acoustic reflex thresholds were estimated for both ipsilateral and contralateral recording using 500, 1000, 2000, and 4000Hz stimuli.

3.5.6 Programming of the digital hearing aid

The hearing aids were programmed using the respective software in the NOAH platform based on an individual’s audiogram. The hearing aids were connected through the NOAH link wireless interface. The gain was prescribed based on the first fit applicable for the naïve hearing aid users using the NAL-NL2 fitting formula. Similarly, three different hearing aids with different channels were programmed for each participant. To avoid confounding variables in the study, all addition features, such as directionality, noise reduction algorithm, and expansion were kept constant. Wide dynamic range compression was used in all three hearing aids.

3.5.7 Hearing aid verification

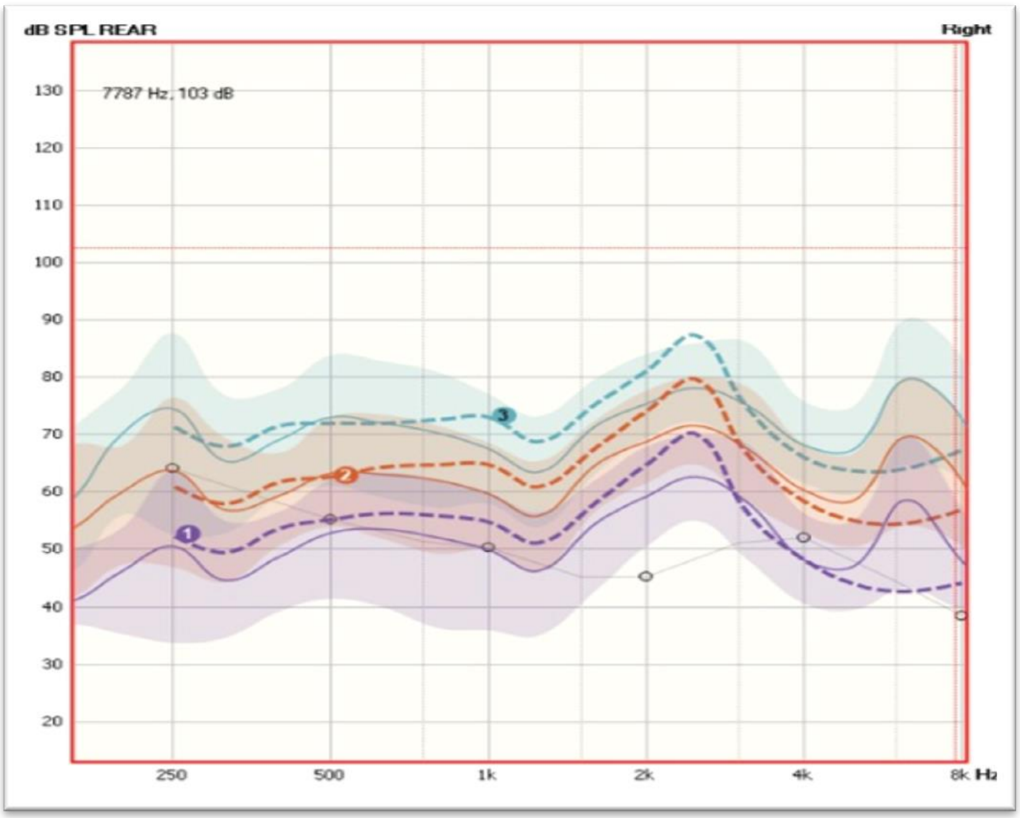
Before the real ear measurement (REM), an otoscopy was performed to make sure none of the subjects had cerumen or wax in their ears. The audiogram was entered into the Aurical system (Otometrics, Denmark). The SPL in the ear canal was determined using a real ear SPL measuring option. Probe tube calibration was done before the placement of the probe inside the ear canal, in inorder to remove the effects of the probe and mic. The subject was seated 1 meter away from the loudspeaker and at an azimuth of 0 (degree) from the loudspeaker. The probe microphone of the Aurical system was inserted into the ear canal of the participant, 5mm near the tympanic membrane. The participants were instructed to maintain the same position during the recording. The hearing aid was switched on and real ear measurements were done using an international speech test signal(ISTS). The same prescriptive formula used for programming the hearing aid was also used to carry out the real ear measurement (NAL-NL2). The measurements were done at 50 dB SPL,65 dB SPL, and 80 dB SPL. The gain in the hearing aid was adjusted via hearing aid programming wherein the hearing aids were simultaneously connected to NOAH software through an interface until the real-ear insertion gain (REIG) matches the target gain curve.

Figure 3.1

The real ear insertion graphical representation of right and left ear of a participant in the present study

Right ear:

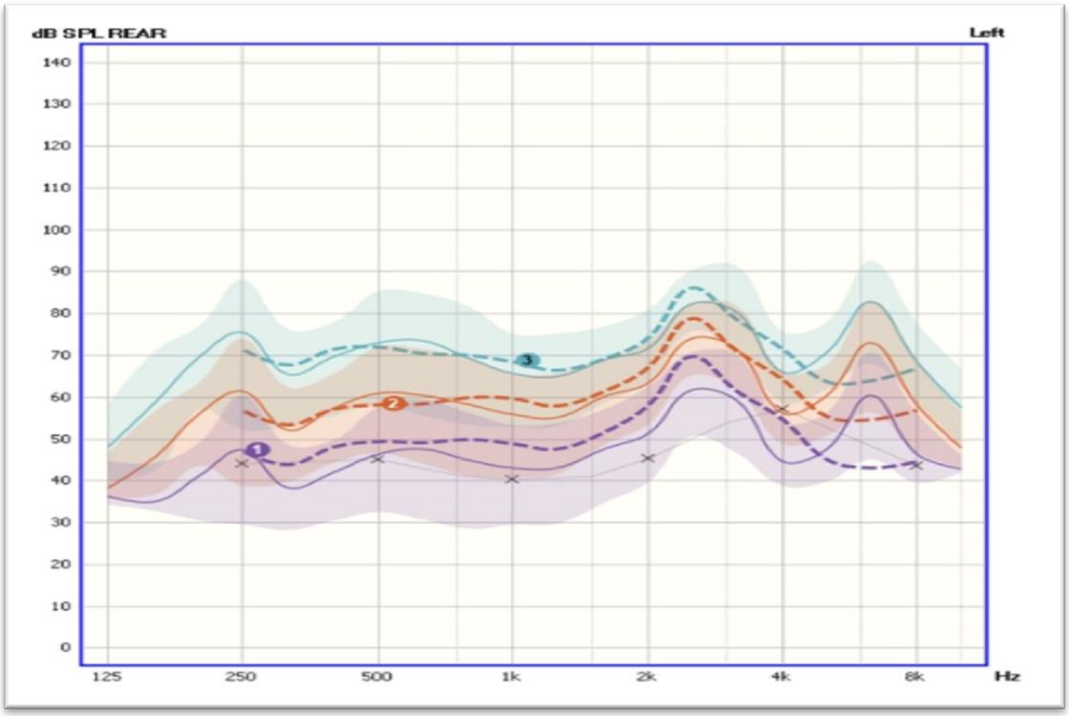
dB SPL



Frequencies (Hz)

Left ear:

dB SPL



Frequencies (Hz)

Note: The dotted line indicates the estimated target level, and the solid line indicates the obtained target in the ear canal across the frequencies. The purple line indicates the target and obtained levels for 50 dB SPL, the orange line is for 65 dB SPL and the blue is for 80 dB SPL.

3.5.8 Assessment of the Spectral Profile Analysis Test

The spectral profile analysis test was assessed using the ‘mlp’ toolbox, which implements the maximum likelihood procedure in MATLAB software (Soranzo & Grassi, 2014). The spectral profile analysis threshold was obtained in four fundamental frequencies. There were four fundamental frequencies used for the profile analysis test

(250Hz, 500Hz, 750Hz, and 1000Hz). In each study random presentation of the frequencies was given to the patients.

The participant in this spectral profile analysis experiment hears three complex tones. Two (the standards) are the same. They all have the same amplitude and have five harmonics. The third tone, or variable tone, has a similar harmonic structure to the standards. Still, its third harmonic component's amplitude is higher, producing a different timbre in comparison to the standards.

The overall level of standards and variables is varied randomly from trial to trial within a range of 5 dB. Onset and offset of tones were gated on and off with two 10-ms raised cosine ramps. This study used the three alternate forced choice (3AFC) approach. The threshold was given in decibels(dB).

The entire stimulus was presented through an audiometer equipped with loudspeakers placed 1 meter away from the listener. The intensity of the presentation will be at 60 dB HL. The complete testing was conducted in a sound-treated double room. Spectral profile analysis threshold was checked with hearing aids having three different 6, 8, and 12 channels monaurally.The participant has to indicate the correct number of stimuli which had the odd timber. Thirty such stimulus trials were presented to the participants. Then, the software gives a numerical value in dB. This value was subtracted from the standard value, and the resulting numerical value was taken as the spectral profile analysis threshold.

CHAPTER 4

RESULTS

The present study aimed to assess and compare the effect of the number of hearing aid channels on auditory stream segregation ability through spectral profile analysis tests in individuals with mild –moderate sensorineural hearing loss**.** The adults (20 ears) in the age range of 18-40 years with mild-moderate sensorineural hearing loss were the participants in the study. Three digital behind-the-ear (BTE) hearing aid models with six, eight, and twelve channels, which were suitable for individuals with mild to moderate hearing loss, were used in the study. The data obtained was analyzed using the statistical package of social science (SPSS) software version 20.0.

Wilcoxon signed ranked test was administered to compare the right and left ear in each of the frequencies and each hearing aid and there was no significant difference between the right and left ear in any of the frequencies and any of the hearing aids ($p>0.05$). Hence, the spectral profile analysis's right and left ear scores were combined and taken as 20 ears for further analysis. Shapiro-Wilk's test of normality was done to check whether the data is normally distributed, and this study's data was found to be normally distributed ($p > 0.05$). Therefore, parametric tests were used to perform inferential statistics.

The results of the study are described under the following headings:

4.1 Descriptive statistics of spectral profile analysis thresholds across the frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) with the 6-channel hearing aid.

4.2 Descriptive statistics of spectral profile analysis thresholds across the frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) with the 8-channel hearing aid.

4.3 Descriptive statistics of spectral profile analysis thresholds across the frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) with the 12-channel hearing aid.

4.4 Comparison of spectral profile analysis threshold between 6,8 and 12-channel hearing aid in all the test frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz).

4.5 Comparison of spectral profile analysis threshold across the frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz) in 6,8 and 12-channel hearing aid.

4.1 Descriptive statistics of spectral profile analysis thresholds across the frequencies with the 6-channel hearing aid

The mean, median, standard deviation (SD), and interquartile range of spectral profile analysis threshold across different frequencies with the 6-channel hearing aid are shown in Table 4.1 and Figure 4.1

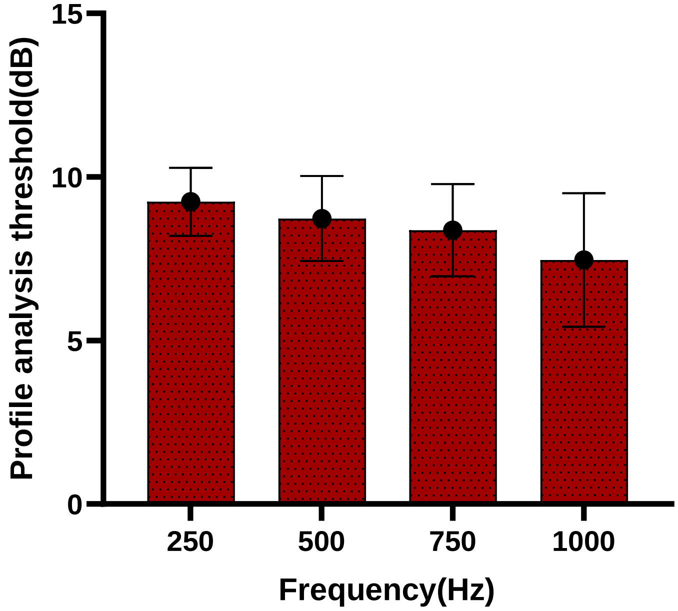
Table 4.1

Mean, Median, Standard deviation (SD), and Interquartile range (IQR) of Spectral Profile Analysis Threshold across Different Frequencies with the 6-Channel Hearing aid

Frequency (Hz)	Mean (dB)	SD	Median	IQR
250	9.24	1.04	9.58	1.02
500	8.73	1.30	8.60	2.07
750	8.37	1.41	8.67	2.71
1000	7.46	2.04	7.87	2.69

Figure 4.1

*Mean and SD of spectral profile analysis threshold (*dB*) across different frequencies with the 6-channel hearing aid.*



The results of the descriptive statistics, as in Table 4.1 and Figure 4.1 showed spectral profile analysis threshold is better at 1000 Hz with 6 channel hearing aid.

4.2 Descriptive statistics of spectral profile analysis threshold across the frequencies with 8-channel hearing aid

The mean, median, standard deviation (SD), and interquartile range of spectral profile analysis threshold across different frequencies with the 8-channel hearing aid are shown in Table 4.2 and Figure 4.2

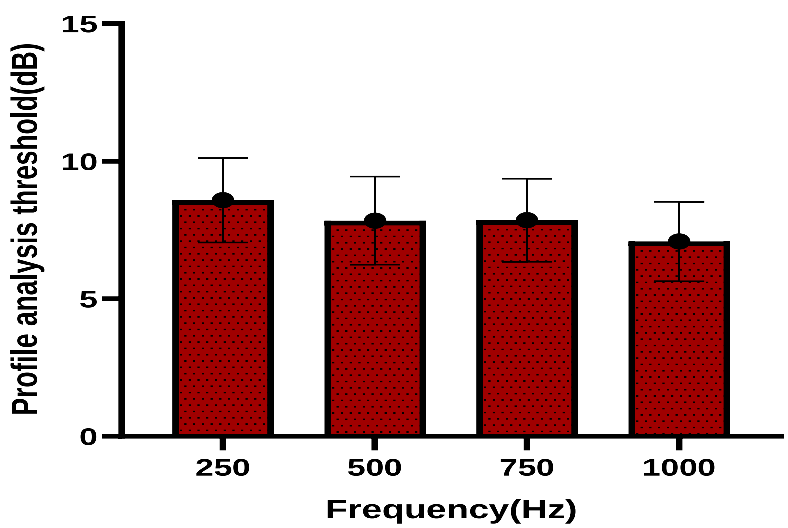
Table 4.2

Mean, Median, Standard deviation (SD), and Interquartile range (IQR) of Spectral Profile Analysis Threshold across Different Frequencies with the 8-Channel Hearing Aid

Frequency (Hz)	Mean (dB)	SD	Median	IQR
250	8.58	1.53	8.56	2.62
500	7.84	1.60	7.87	2.76
750	7.86	1.51	8.04	2.69
1000	7.08	1.45	6.88	2.60

Figure 4.2

Mean and SD of spectral profile analysis threshold (dB) *across different frequencies with the 8-channel hearing aid*



The results of the descriptive statistics, as in Table 4.2 and Figure 4.2 showed spectral profile analysis threshold is better at 1000 Hz with 8-channel hearing aid.

4.3 Descriptive statistics of spectral profile analysis threshold across the frequencies with the 12-channel hearing aid

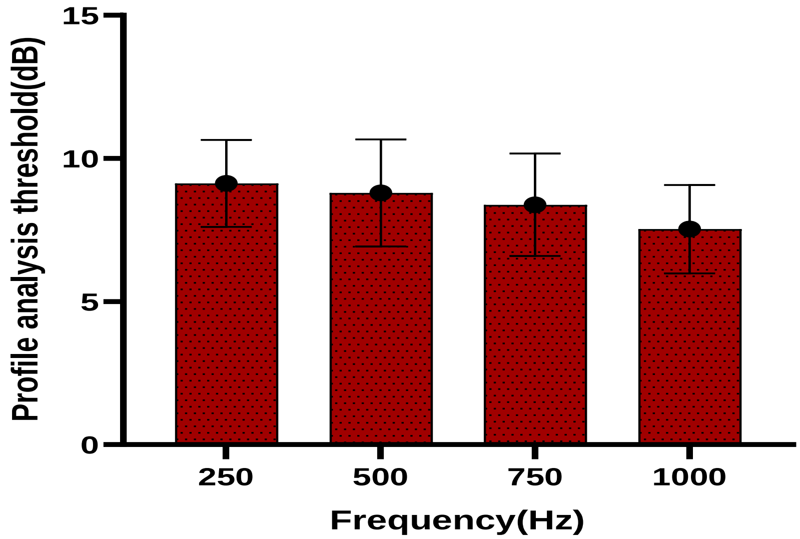
The mean, median, standard deviation (SD), and interquartile range of spectral profile analysis threshold across different frequencies with 12 channel hearing aids are shown in Table 4.3 and Figure 4.3

Table 4.3

Mean, Median, Standard deviation (SD), and Interquartile range (IQR) of Spectal Profile Analysis Threshold across Different Frequencies with 12-Channel Hearing Aid

Frequency (Hz)	**Mean (dB)**	**SD**	**Median**	**IQR**
250	9.13	1.52	9.33	2.84
500	8.80	1.87	9.30	3.07
750	8.38	1.79	9.22	3.04
1000	7.53	1.54	7.97	2.82

Figure 4.3 *Mean and SD of Spectral Profile Analysis Threshold (*dB*) across Different Frequencies with 12-Channel Hearing Aid*



The results of the descriptive statistics, as in Table 4.3 and Figure 4.3 showed spectral profile analysis threshold is better at 1000 Hz with 12 channel hearing aid.

4.4 Comparison of spectral profile analysis threshold between 6, 8, and 12-channel hearing aids in all the test frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz).

Shapiro-Wilk's test of normality was done, and the results showed that the data was normally distributed ($p>0.05$). Hence, parametric inferential statistics were administered. Two-way repeated measure ANOVA was done to compare the profile analysis threshold between 6,8, and 12-channel hearing aids in all the test frequencies. The two-way repeated measure ANOVA test results showed no significant difference in the profile analysis threshold between the 6,8 and 12-channel hearing aids.[$F(2,38) = 2.473$, $p>0.05$, $\eta_p^2 = 0.115$].The result indicated that spectral shape discrimination was perceived equally through all the hearing aids irrespective of number of channels in the hearing aid.

4.5 Comparison of spectral profile analysis threshold across the frequencies in 6, 8, and 12-channel hearing aids.

Shapiro-Wilk's test of normality was done, and the results showed that the data was normally distributed ($p>0.05$). Hence, parametric inferential statistics were administered. Two-way repeated measure ANOVA was done to compare the profile analysis threshold across the frequencies in 6,8 and 12-channel hearing aids. The two-way repeated measure ANOVA test results showed that there was a significant main effect of frequencies [$F(3,57) = 10.487$, $p<0.01$, $\eta_p^2 = 0.356$]. Since there was a significant difference across frequencies, the Bonferroni post hoc test was done to see between which frequencies there was a significant difference. Results obtained suggest that there is a significant difference between 250 Hz and 1000 Hz also, there is a significant difference between 500 Hz and 1000 Hz ($p <0.05$). This result indicates that spectral profile analysis is better when the test fundamental frequency is 1000 Hz.

Table 4.4

Bonferroni Post Hoc Test Results for Spectral Profile Analysis Threshold across Frequencies

(I) frequency	(J)frequency	Mean difference(I-J)	Significance
	250 Hz	-1.625	.001
1000 Hz	500 Hz	-1.095	.007
	750 Hz	.318	.092

Results obtained suggest that there is a significant difference between 250 Hz and 1000 Hz also, there is a significant difference between 500 Hz and 1000 Hz ($p < 0.05$). This result indicates that spectral profile analysis is better when the test fundamental frequency is 1000 Hz.

The present study shows that there is a main effect of frequency, and there is no main effect of hearing aid channels as well. Also, there is no interaction between these two (frequency and channels in the hearing aid). The two-way repeated measure ANOVA test results showed that there was no significant interaction effect of frequencies and channels in the hearing aids [$F(6,114) = 0.324$, $p > 0.05$, $\eta_p^2 = 0.017$] .As there is no interaction effect in the study, we can assume that the frequency main effect can be seen in all three hearing aids.

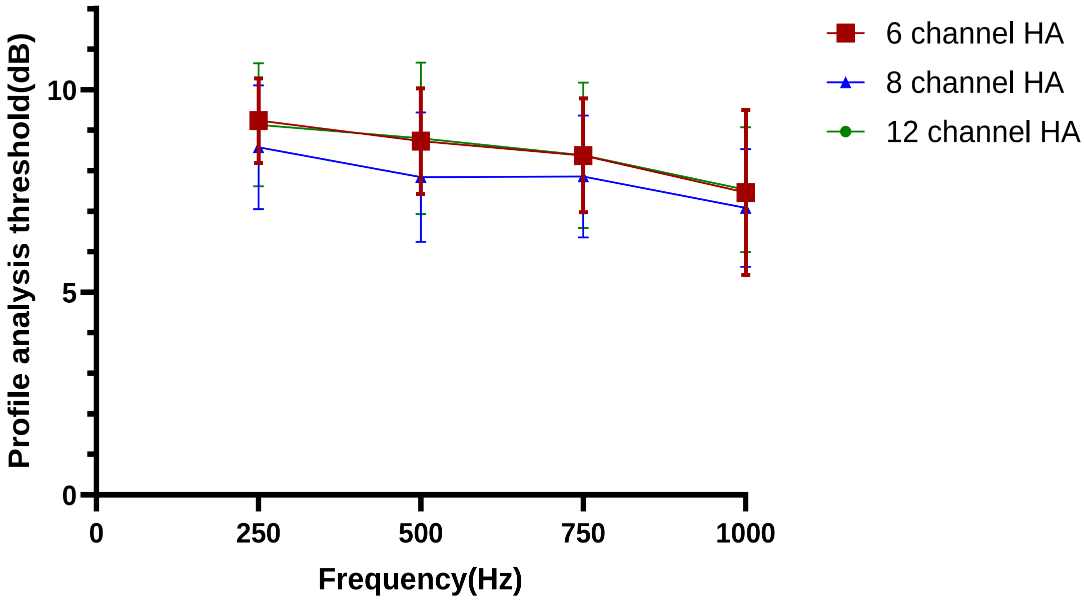


*Figure 4.4 Mean and SD of spectral profile analysis threshold (*dB*) between 6,8 and 12 channel hearing and across the test frequencies.*

As shown in Figure 4.4 spectral profile analysis threshold was better with 8 channel hearing aid but not statistically significant,also spectral profile analysis threshold was better at 1000 Hz.

CHAPTER 5

DISCUSSION

The objective of this study is to find the effect of the number of channels in the hearing aid on the spectral profile analysis threshold in individuals with hearing impairment. The results obtained are discussed elaborately in the following sections:

5.1 Comparison of spectral profile analysis threshold between 6,8,12-channel hearing aid in all the test frequencies (250 Hz, 500 Hz, 750 Hz, and 1000 Hz).

Sensorineural hearing loss is characterized by damage to the sensitive hair cell in the inner ear or the damage to the auditory nerve. People with hearing loss have difficulty understanding speech in situations involving stream segregation, such as those when there is background noise, compared to people with normal hearing. Poor performance in spectral profile analysis was observed in individuals with cochlear hearing loss because of the abnormal spectral processing of auditory signal at the basilar membrane and poorer performance in individuals with auditory neuropathy spectrum disorder (ANSD) is due to the asynchronous firing of auditory neurons which negatively affect the spectral and temporal cue extraction by the central auditory system (Banerjee & Prabhu, 2021b). By amplifying sound, hearing aids (HAs) can help people with hearing loss partially restore their auditory threshold, which is important for increasing their ability to recognize speech. The loss of sensitivity can be efficiently compensated for by amplification, but under challenging listening conditions, more complex signal processing is needed (Kollmeier & Kiessling, 2016). The rationale of multichannel compression is to split the audible frequency range into independent frequency channels and apply processing schemes such as amplitude compression in specific frequency regions for better listening outcomes. Many studies investigated the effect of increasing the number of channels and results showed conflicting findings. The literature in this field is muddled by a large variety of factors such as variations in research design, test material, and the compression behavior itself (Menzel, 1994).

Several studies showed the positive effect of increasing the number of channels in the hearing aid as improved speech discrimination in noise (Yund & Buckles, 1995), spectral cue perception (Huebert & Brennan, 2022), speech intelligibility in individuals with sloping hearing loss (Jyoti & Singh, 2011; Kates, 2010). In contrast, there is literature evidence that shows the negative effect of increasing the number of channels in the hearing aid (Bor et al., 2008; Plomp, 1988). This negative effect can be attributed to the channel interaction (Walker et al., 1984), spectral shape alteration (Bustamante & Braida, 1987), and channel summation effect (Kuk & Ludvigsen, 2003) that can occur in a multichannel hearing aid.

Interestingly, some studies show no significant effect of the number of channels in a hearing aid on consonant or vowel identification (Crain & Yund, 1995), speech intelligibility, and quality (Keidser & Grant, 2001). However, most of the studies investigated the effect of number of channels in a hearing aid on speech discrimination, speech intelligibility, quality, music perception, vowel and consonant perception, and spectral cue perception, specifically none of the studies investigated the effect of number of channels in hearing aid on spectral profiling, which also give an insight about the auditory streaming as well. The results of the present study revealed there is no significant difference between the spectral profile analysis threshold across 6,8 and 12-channel hearing aids. This study contradicts the negative effect of increasing the number of channels in a hearing aid. The negative effect of multichannel compression (MCC) can only occur in extreme MCC conditions. Studies that showed a negative effect were mostly done in moderately severe-severe hearing loss individuals, and the compression ratio was high. The reduction in the spectral contrast was mainly due to the interaction of a high compression ratio and a larger number of channels. The present study was done in individuals with mild-moderate sensorineural hearing loss and the compression ratio was set according to the amount of loss that individual has at a specific frequency range.

In the present study, the spectral profile analysis threshold was better with the 8-channel hearing aid, though the difference was not statistically significant. So 8-channel hearing aid can better identify the change in the spectral shape of complex stimuli than a 6-and 12 channel hearing aid. This finding was consistent with the literature evidence, which showed an improvement in speech discrimination and recognition with an eight-channel hearing aid (Jyoti & Singh, 2011; Yund & Buckles, 1995). An eight-channel hearing aid can utilize the effect of multichannel compression. As the difference is not statistically significant, the present study concluded that the identification of change in the spectral shape is equivalent in 6,8, and 12-channel hearing aids. The analysis band and the compression channel in the hearing aids have gradual filter slopes. If the filter slope of the channels and the bands are more gradual, the compression across the channels will be more correlated. In that case, the hearing aid with a larger number of channels will perform similarly to a smaller number of channels (Woods et al., 2006).

5.2 Comparison of spectral profile analysis threshold across the frequencies in 6, 8, and 12-channel hearing aids.

In the present study, it was found that there was a significant main effect of frequency. When comparing all the test frequencies, the spectral profile analysis threshold was better with 1000 Hz. This difference might be due to the major harmonics of the test stimuli (1000 Hz) falling in the high-frequency region and the effectiveness of the number of channels in the same region. A 6-channel hearing aid has three different frequency channels, 8- channel has five different frequency channels, and 12-channel has seven different frequency channels after 1000 Hz. This helps better and accurately fit thresholds in high frequencies, thereby helping in better identifying the spectral shape. This assumption is consistent with earlier literature which showed better performance in speech identification scores using high-frequency word lists with increase in the number of channels (Jyoti & Singh, 2011).

CHAPTER 6

SUMMARY AND CONCLUSION

The ability of the auditory system to segregate different sounds and group similar sounds is called auditory streaming or, auditory stream segregation, or auditory scene analysis. This ability helps in better speech understanding in noisy environments. Many spectral and temporal cues can be used to interpret an auditory scene. Spectral profiling is one of the important spectral cues. The ability of our auditory system to detect the change in the spectral shape when the amplitude of one of the components of the complex tone is changed can be measured psychoacoustically. Some studies show reduced spectral profile analysis threshold in individuals with hearing loss. Hearing aids can increase the audibility of the sounds, and more sophisticated signal processing should be used in an adverse listening environment. So this study aims to assess and compare the effect of the number of channels in the hearing aid on spectral profile analysis threshold in individuals with hearing impairment.

Twenty ears with mild-moderate sensorineural hearing loss were included in the study. The age range of participants was 18-40 years (mean years = 32.2, SD = 7.9). The hearing aids were programmed for the first fit using the NAL-NL2 prescriptive formula. Hearing aid verification was done using an Aurical free fit (Otometrics, Denmark). The spectral profile analysis threshold was obtained using the 'mlp' toolbox, which implements the maximum likelihood procedure in MATLAB software. Spectral profile analysis threshold was obtained with 6,8, and 12-channel hearing aid in all the test frequencies monoaurally.

The data were analyzed using a statistical package for the social sciences(SPSS) version 20. Two-way repeated measure ANOVA was done to compare the profile analysis threshold between 6,8 and 12-channel hearing aids in all the test frequencies. Results showed no significant difference in the spectral profile analysis threshold between the 6,8 and 12-channel hearing aids. Two-way repeated measure ANOVA was done to compare the profile analysis threshold across the frequencies in 6,8 and 12-channel hearing aids. Results showed that there was a significant main effect of frequencies. Since there was a significant difference across frequencies, the Bonferroni post hoc test was done to see between which frequencies there was a significant difference. Results obtained suggest that there is a significant difference between 250 Hz and 1000 Hz and a significant difference between 500 Hz and 1000 Hz. Spectral profile analysis threshold is better with 1000 Hz. This might be due to the effective number of channels available in the hearing aid, predominantly in the high frequencies.

6.1 Implication of the Study

- The study helps to understand the effect of number of channels in a hearing aid on spectral profile analysis, which might also give an insight about auditory streaming.
- This study helps to understand the frequency effect in multichannel hearing aids.
- This would help counsel the patients regarding the usefulness of multichannel amplification and the number of channels that can be useful for the patient.

6.2 Future directions

- The study of the effect of the number of channels in other spectral and temporal auditory streaming cues.
- To study the effect of multichannel and channel-free hearing aids on spectral profiling.
- To study the effect of multichannel amplification in spectral profiling in children.
- To study the number of channels in hearing aids on spectral profiling in individuals with various degrees of hearing loss and configuration.

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