Comparison of ChannelFree™ and Multi Channel Hearing Aids on Performance in Indviduals with Sensorineural Hearing Loss

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MAY 2017

Dedicated to

Amma
Pappa
Akka

CERTIFICATE

This is to certify that the dissertation entitled 'Comparison of ChannelFree^{TM} and Multichannel Hearing Aids on Performance in Indviduals with Sensorineural Hearing Loss' is the bonafide work submitted in part fulfillment for the degree of Masterof Science (Audiology) of the student (Registration No. 15AUD026). 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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This is to certify that the dissertation entitled '**Comparison of ChannelFree^{TM} and Multi Channel Hearing Aids on Performance in Indviduals with Sensorineural Hearing Loss'** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

Thisistocertify thatthisdissertationentitled '**Comparison of ChannelFree™ and Multi Channel Hearing Aids on Performance in Indviduals with Sensorineural Hearing Loss'** isthe result of my own study under the guidance of Dr. Manjula P., Professor in Audiology Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and hasnotsubmittedearlierinany otherUniversityfor the award of anyDiplomaor Degree.

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Happy reading

Abstract

Individuals with sensorineural hearing loss with flat and sloping configuration, face major problems such as reduced audibility, reduced dynamic range, reduced frequency selectivity and impaired temporal resolution giving rise to poor speech intelligibility and listening discomfort, in quiet as well as in adverse listening situations. Multichannel hearing aids with wide dynamic range compression made their way in order to resolve these issues. ChannelFree™ hearing aids were developed claiming to improve speech intelligibility and listening comfort. To see the effect of channel, a comparison of three-channel, five-channel and ChannelFree™ hearing aids, in ears with flat and sloping SNHL, was done by collecting data for SIS in quiet using phonemically balanced words for flat SNHL group and high frequency words for sloping SNHL group, SNR-50 and quality rating from eleven ears of participants with flat SNHL and ten ears of participantswith sloping SNHL. The results revealed more benefit from ChannelFree™ hearing aid processing in flat and sloping SNHL groups compared to three-channel and five-channel hearing aid in the presence of noise (SNR-50) and parameters of quality perceived better in all except loudness with ChannelFree™ processing which was softer compared to three-channel and five-channel hearing aids. Non-parametric tests revealed more benefit from ChannelFree™ hearing aid processing in flat SNHL group of population compared to sloping SNHL group of population. Hence, the present study suggests ChannelFree™ hearing aid processing as a better amplification method for individuals with flat and sloping configuration of sensorineural hearing loss as it provides better speech perception in the presence of noise and better quality of life.

Keywords: *Multichannel, ChannelFree™, Speech identification, SNR-50, Quality.*

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

The major problems faced by individuals with sensorineural hearing loss (SNHL) is reduced audibility, reduced dynamic range, reduced frequency selectivity (Moore & Glasberg, 1997) and impaired temporal resolution (Nelson et al., 1997) giving rise to poor speech intelligibility and listening discomfort, in quiet as well as in adverse listening situations.In SNHL, the damage to outer hair cells (OHC) produces cochlear amplifier function (Dallos, 1973), wider auditory filters (Glasberg & Moore, 1986), and neural asynchronous firing to varying acoustic cues (Tremblay, 2005). With the advent of digital hearing aids, amplification has been found useful for types and degrees of hearing loss and also in different listening conditions.

To compensate for reduced audibility and reduced dynamic range, hearing aids have incorporated amplification and compression in order to improve speech audibility and comfort. The main goal of hearing aids is to amplify sounds such that it is audible and comfortable. The compression reduces gain for high level signals and amplification increases gain for low level signals (Johnson, 1993; Killion, 1996). The main rationale for splitting the audible frequency range into independent channels was to apply processing schemes such as amplitude compression in specific frequency region, also known as Wide Dynamic Range Compression (WDRC) (Bor et al., 2008).

Even though WDRC is providing a solution , a few aspects needs to be investigated in order to choose fast acting compression or slow acting compression in order to improvise speech intelligibility and listener comfort (Moore, 2008). According to Moore (2008), fast systems have attack and release times between 5 and 200 ms, whereas slow systems have attack and release times exceeding 500 ms. In a speech signal, the most intense sounds (vowels) are 30 dB greater than the weakest sounds (unvoiced consonants). Consequently, the time constants used in a WDRC system can have a significant effect on the intelligibility and comfort of the speech signal (Dillon, 2001).The time constants used in WDRC hearing instruments can result in a trade-off between speech intelligibility (fast acting) and listening comfort (slow acting) for the end user.

Fast-acting multichannel WDRC may negatively affect listening comfort due to overshoot and spectral distortion (Schaub, 2010). Since fast-acting WDRC provides more amplification to consonants than to vowels, overshoot occurs at the onset of each vowel that follows a consonant. In fact, Moore (2008) reported that fast-acting compression causes spurious changes in the temporal envelope that could be avoided by delaying the input signal relative to the gain control signal. Overshoot rarely occurs in slow-acting WDRC as the long time constants result in constant gain values during running speech.Spectral distortion occurs with fast-acting WDRC systems that utilize multiple channels (Schaub, 2010). Moore (2008) suggested that fast-acting compression in multiple channels creates spectral distortion because the patterns of gain across frequency change so rapidly over time. As with overshoot, spectral distortion rarely occurs with slow-acting WDRC as the long time constants result in a more linear effect when processing speech.

Yund and Buckles (1995) reported that fewer channels / bands in hearing aids help individuals with sloping sensorineural hearing loss to perceive speech as clear. They evidenced at least eight channels to be incorporated in hearing aids which are sufficient to provide information across frequency bands since there was no performance difference between eight channel and twelve channel hearing aids while speech scores improved from four channels to eight channels. They stated the drawbacks of multichannel amplification as formant disruption, timbre disruption and co-articulation which interferes with sound quality and speech intelligibility (Dillon, 2001). But according to McDermott and Dean (2000), individuals with sloping sensorineural hearing loss exhibit increasingly reduced dynamic range across frequency and such individuals get minimum benefit from the eight channel or multichannel digital hearing aids due to temporal smearing or spectral temporal distortion by compression. Bor et al. (2008) is of the opinion that the appropriate number of channels remains unanswered in case of multichannel compression.

In order to overcome limitations of eight channel or multichannel hearing aids, ChannelFree™ hearing aids were developed claiming to improve speech intelligibility and listening comfort (Schaub, 2010). The manufacturer claims that the ChannelFree™ digital signal processing assesses incoming signals at phonemic speed; even the shortest speech unit (the phoneme) is amplified precisely according to its particular intensity. The main goal of channelFree™ processing is to amplifythe low-level parts of speech without over amplifying highlevel sounds which is usually seen in fast acting compression. The typical characteristic of channelFree™ hearing aid is that it detects and operates on wideband signal while still providing variable compression ratios across frequency and adjusts the gain 20,000 times per second without dividing the signal into fixed channels or bands

(Schaub, 2008). Each phoneme is analyzed and adjusted 2000 times.These advanced features in ChannelFree™hearing aids help it to recognize eventhe shortest as well as theweakest speech segments. This allows applying instantaneousand accurate gain with less distortion (Kodiyath, Mohan,&Bellur, 2017).ChannelFree™ processing provides clear and natural sound quality.ChannelFree™ processing has the highest temporal resolutionof any hearing system by providing correct amplification of the smallest parts of speech. According to Dillon et al. (2003), ChannelFree™ processing has been shown to have the highest rated sound quality for speech and music when compared to multi-channel hearing aids. It has been reported that channelFree™processing retains the spectral contrast and also facilitate temporal cues from the amplified speech in noise(Kodiyath, Mohan, &Bellur, 2017).

Schaub (2008) reported that the working principle of channelFree™ hearing aids closely resembles cochlear non-linearity by providing a higher gain to low level signal and compressing a high level signal. One distinctive feature of channelFree™ processing as reported by the manufactureris an extremely short reaction time of 10 ms, such short reaction time can cause distortion problem in conventional compression systems (Schaub, 2010).The channelFree™analyzes and adjusts gain 20,000 times per second, i.e., each phoneme is analysed and adjusted on average 2,000 times. This results in each phoneme receiving the amplification it needs, with soft unvoiced consonants receiving moregain than loud vowels. Thus, channelFree™ processing acts more like the healthy cochlea. As it analyses and adjusts20,000 times, the spectral and temporal resolution is much better to provide clear and natural sound.The present study aims at comparing the speech perception, in quiet and noise, with multichannel and channelFree^{TM} hearing aids for persons with different configurations of sensorineural hearing loss.

Need for the study

It has been documented in literature thatChannelFree hearing aids arebetter when compared with regular multichannel hearing aids on speech identification performance (Hemanth et al., 2016)for individuals with sloping sensorineural hearing loss. ChannelFree hearing aids are reported to provide listening comfort and better speech intelligibility (Schaub, 2010).Plyeret al., (2013) has reported better speech scores in individuals with mild to moderately severe sloping sensorineural hearing loss (SNHL) using open fit receiver in the canal (RITE)hearing aids (.Kumar (2007) showed that individuals with sloping SNHL performed better with ChannelFree hearing aids in quiet and in noise with constant SNRs (i.e., +10 dB & 0 dB SNR) when compared to single channel and multichannel (4 and 8) hearing aids. In his study, the hearing aids chosen were from different companies. It would be interesting to study the effect of ChannelFree and multichannel hearing aids from the same company to ensure the similar technology. They have also tried to account for speech intelligibility in both quiet and in the presence of noise but information on the quality of speech signal as perceived by the participants could have been added more valid information which is been considered in the present study.

ChannelFree^{TM} processing was designed to address the limitations of fast-acting multichannel WDRC in order to solve the trade-off between speech intelligibility and listener comfort (Schaub, 2008).Since the routine hearing aid evaluations are generally carried out in quiet condition, the outcome of the hearing aids cannot be ideally generalised to day-to-day natural situations, where the hearing aid wearer will be in noisy background. Evidence shows that individuals with hearing impairment demonstrate marked reduction in speech recognition scores in the presence of noise compared to individuals having normal hearing (Cohen & Keith, 1976; Leshowitz, 1977). To address this situation, aided SNR-50 evaluation for both multichannel hearing aids and ChannelFree™ hearing aids arecarried out for the two groups, those with flat and those with sloping SNHL, to determine the speech recognition ability in quiet and in the presence of background noise.

Since the ChannelFree™ hearing aid processes the signal 20,000 times, and does not split frequency band, the gain or amplification provided in such processors, should not compromise for the comfort in hearing aid users.

Aim of the study

To compare the effect of ChannelFree^{TM} processing in hearing aids for individuals with different configurations of SNHL,in quiet and noise, with multichannel hearing aids.

Objectives:

The major objectives taken up in the present study are:

1. To evaluate the performance on speech identification in quiet with ChannelFree^{TM} hearing aids in individuals with flat SNHL and sloping SNHL.
2. To evaluate the performance on speech identification in quiet with multichannel hearing aids in individuals with flat SNHL and sloping SNHL.
3. To evaluate the performance on speech identification in noise, with ChannelFree^{TM} hearing aids in individuals with flat SNHL and sloping SNHL.
4. To evaluate the performances on speech identification in noise,with multi channel hearing aids in individuals with flat SNHL and sloping SNHL.
5. To compare the speech perception in quiet with channelFree^{TM} and multi channel hearing aids between flat SNHL and sloping SNHL.
6. To compare the speech perception in noise with channelFree^{TM} and multi channel hearing aids between flat SNHL and sloping SNHL.
7. To evaluate the efficacy of channelFree^{TM} and multi channel hearing aids on quality of speech between individuals with flat SNHL and sloping SNHL.

Chapter 2

Literature Review

Individuals with sensorineural hearing loss (SNHL)s face problems such as decreased audibility, decreased dynamic range, decreased frequency resolution and decreased temporal resolution. Any of these problems or in combination can cause decrease in speech perception. An appropriate hearing aid will overcome this problem to an extent. The main goal of hearing aids is to amplify sounds such that it is audible and comfortable.

Our everyday speech includes such a wide range of intensity levels, from low-intensity consonants such as /f/ to high-intensity vowels such as /i/, and from whispered speech to shouting (ref). The benefit from a linear hearing aid is restricted when the amplification is needed to make low intensity sounds audible, amplifies high intensity sounds to the point of discomfort. Smaller the dynamic range in a sensorineural hearing loss, more is the difficult to make speech audible in a variety of situations. To fit the large dynamic range of natural acoustic signals into reduced dynamic range of listeners with hearing impairment , dynamic compression was investigated in several studies (Braida, 1979; Plomp, 1988).

Most hearing aids now offer some form of compression in which gain is automatically adjusted based on the intensity of the signal. The compression reduces gain for high level signals and amplification increases gain for low level signals (Johnson, 1993; Killion, 1996). High intensity signals (such as shouted speech), will have higher compression ratio in each channel (Souza & Turner, 1999). The present study aimed at investigating the effect of channelFree and multichannel hearing aid processing on speech perception and quality measures. The literature relevant to the study has been given under the following headings:

2.1 Perception through multichannel hearing aid processing in quiet

2.2 Perception through multichannel hearing aid processing in noise

2.3 Perception through ChannelFree™ hearing aid processing in quiet and in noise

2.1 Effect of multichannel compression on speech identification in quiet

Humes et al. (1999) took 55 individuals with hearing impairment with linear peak clipping (fit according to linear, NAL-R targets) and two-channel WDRC aids (fit according to non-linear, DSLi/o targets). All the subjects wore the linear aids for two months, followed by the WDRC aids for two months. At the end of each two-month trial period, a battery of outcome measures were completed that included word recognition in quiet and in noise at various presentation levels; judgment of sound quality; and subjective ratings of hearing aid benefit. In general, the results showed better speech intelligibility with the WDRC aid at all but high level inputs. Patients also reported that the WDRC hearing aids provided greater ease of listening for low level speech in quiet. The authors have attributed these results to the greater gain at low input levels provided by the WDRC circuit and the higher DSL target gain levels for the WDRC aid.

Flynn et al. (2004) took 21 children with severe hearing loss for a study to compare performance on measures of audibility, speech understanding (in quiet and noise) and listening situations between the children’s current analog hearing aids and a test hearing aid with multiple-channel non-linear compression. The data on audibility, speech understanding in quiet and in noise, and listening skills were obtained from children at 2 weeks, 8 weeks, 6 months and 12 months following the fitting of a multiple-channel non-linear hearing aid. Compared with the children's own hearing instruments, the test instruments provided improved audibility, improvement in speech understanding in quiet and noise, and an improvement in listening skills. They found that there is improvement in speech identification score (SIS) in quiet condition with multichannel hearing aid. In this experiment, the effect of acclimatization has been accounted very well with the improvement in the performance. Since the study was conducted on children, the outcome measures for quality of speech signal would play greater role since they are in developmental stage. More the quality of speech signal, better will be the development of speech and language skills in children with hearing impairment.

With a large number of compression channels, relative differences in level across frequency (i.e., spectral peak-to-valley differences) will be reduced. Therefore, use of more than two or three channels may substantially reduce the frequency distinction in the speech signal, potentially degrading temporal and spectral cues (Bustamenete & Braida, 1987; Dreschler, 1992; Moore & Glasberg, 1986). Any negative effects of increasing numbers of channels are likely to have the greatest consequences for sounds that carry pertinent information in the spectral domain; among them, vowels or the nasal consonants /m, n, ng/ (Kent & Read, 1992). For example, the most important cue for vowel identity is detection of spectral peaks relative to the surrounding frequency components. Even if overall audibility of the sound is improved, these changes may reduce intelligibility. Differences in the number of channels could explain differences in results between investigators who demonstrate improved vowel intelligibility using WDRC with a small number of channels (Dreschler et al., 1988 & 1989; Stelmachowicz et al., 1995) and those who show a detrimental effect (Franck et al., 1999) showed vowels were harder to identify via an eight-channel compression hearing aid than a single channel compression hearing aid. In a review of published data on multichannel amplification prior to 1994, Hickson (1994) concluded that the best results were obtained with compression systems having three or fewer channels. For speech intelligibility in general, recent data suggest that multi-channel systems with up to four channels are equivalent to, but not superior to, single channel systems (Keidser & Grant, 2001; van Buuren et al., 1999).

For studies that demonstrated improved performance with greater number of channels, the advantage appears to be one of improved audibility rather than the number of channels. For example, Yund and Buckles (1995b) demonstrated improved nonsense syllable recognition in noise as the number of channels increased from four to eight. Comparison of consonant confusions and frequency response for the different number of channels were consistent with improved high-frequency audibility. The authors note that results of multi channel compression experiments should be interpreted in the context of the stimuli used. In this case, no additional improvement was seen with more than eight channels, perhaps because the eight-channel system already provided sufficient information for the recognition of high-frequency consonants. Similarly, Braida et al. (1982) pointed out that some early studies showed a large advantage for multichannel compression provided improved high-frequency audibility relative to a linear condition.

To summarize, increasing number of channels on speech intelligibility in quiet have adverse effects. Increasing up to four channels from single channel does not make significant difference on speech intelligibility in individuals with sensorineural hearing loss. As number of channel raises from four to eight, audibility has been observed to improv thereby increasing the performance or speech intelligibility.

According to Yund and Buckles (1995), for most audiometric configurations, two-channel or three-channel compression hearing aids seem to offer a good compromise between customized manipulations of the hearing aid response and providing coherent spectral contrast. For more unusual audiometric configurations (i.e., rising or cookie bite audiograms), larger numbers of channels are appealing. Available data on larger number of channels is mixed, although larger number of channels should be most advantageous when adequate frequency shaping is required (Crain & Yund, 1995).

Bor et al. (2008) studied the effect of reduced spectral contrast on vowel identification using multichannel compression. Eight vowels produced by 12 talkers in the /hVd/ context were compressed using 1, 2, 4, 8, and 16 channels. Formant contrast indices (mean formant peak minus mean formant trough; maximum formant peak minus minimum formant trough) were developed to quantify spectral changes. Twenty listeners with mild to moderately severe sensorineural hearing loss identified the compressed vowels in an 8-alternative forced-choice procedure. Formant contrast measures revealed significant spectral flattening for 6 of the 8 vowels as the number of channels increased. A significant decrease in vowel identification performance was also observed as spectral contrast decreased. The author concluded increasing the number of wide dynamic range compression channels may not be beneficial for all speech signals, and individual vowel identification performance can vary greatly for listeners with similar hearing loss.

When vowels, diphthongs and other phonemes are processed by a multichannel instrument, their key formant sounds may be managed and resolved by different channel, receiving more or less amplification and compression than was originally present and intended. This possible outcome distorts relationships among formants and potentially other key features of vowel, phoneme and word recognition. Spectral cues in general, are perhaps the most relevant feature for speech reception. Distorted spectral coding appears to be related to reduce speech perception in noise, whereas distorted intensity and temporal cues are not (van Schijndel et al., 2001). Another consideration is that the number of channels, compression ratios, and their time constants (attack and release times) interact. Taken to an extreme, a large number of channels with high compression ratios can result in an amplified signal (Plomp, 1998) stripped of many of the identifiable speech elements. This effect is known as ‘spectral smearing.’ Because of the distorted formant information, spectral smearing is most deleterious for ‘place’ of consonant articulation (eg. Difficulty discriminating between /b/, /d/ and /g/), and increases susceptibility to noise (Boothroyd et al., 1996).

Boothroyd and colleagues (1996) found that spectral smearing within bandwidths of 707 and 2000 Hz elevates the threshold for phoneme recognition in noise by about 13 and 16 dB respectively. In addition, spectral smearing has greater degradation on word, rather than phoneme performance due to the non-linear relationship between these two measures. This implies that the real world deleterious effect on speech in noise would likely be extreme. In fact, spectral smearing alone can reduce phoneme recognition to only 12% (Boothroyd et al., 1996). This finding is consistent with the results of van Schijndel et al. (2001) who found that distorted coding of spectral cues was the main factor associated with reduced speech discrimination in noise for those with hearing impairment. Distorted coding of spectral cues had greater negative impact than did distorted temporal or distorted intensity cue coding. When the input signal is broken into channels, the spectro-temporal characteristics become distorted and important information on speech transiton is lost, which has been found to impair speech understanding (Boothroyd et al., 1996).

2.2 Effect of multichannel compression on speech identification in noise

An important issue is the ability of compression amplification to improve speech intelligibility in noise. Although initially expected as a benefit of non-linear amplification, compression does not appear to provide substantial benefit in noise compared to linear amplification (eg, Boike & Souza, 2000; Dreschler et al., 1984; Hohmann & Kollmeier, 1995; Kam & Wong, 1999; Nabelek, 1983; Stone et al., 1997; van Buuren et al., 1999; van Harten-de Bruijn et al., 1997). This is certainly not the case when compared to a directional microphone (Ricketts, 2001; Valente, 1999; Yueh et al., 2001). In earlier attempts to account for the communication loss reported for listeners with selective high frequency information, the threshold dip has been regarded as selective attenuation of high frequency information. This, together with the limited dynamic range (i.e., recruitment) in the region of threshold elevation has been held responsible for the loss speech discrimination in noise (Leschowitz, 1977).

Some investigators have suggested that the modulation properties of the background noise may influence the benefit of compression (Boike & Souza, 2000b; Moore et al., 1999; Stone et al., 1999; Verschuure et al., 1998). Specifically, compression may improve intelligibility when the background noise is modulated instead of unmodulated.

Bentler and Duve (2000) tested a variety of hearing aids that represented advances in amplification technology during the 20th century. Among the devices was a linear peak clipping analog aid, a single channel analog compression aid, a two-channel analog WDRC aid, and two digital multichannels WDRC aids, all hearing aids were behind–the-ear type. Each device was fit using its recommended prescriptive procedure; NAL-R for the linear aid, FIG6 for the single channel compression hearing aid, and the manufacturers' proprietary fitting algorithms for the remaining devices. Despite the differences in circuitry, speech recognition scores in quiet and in noise were similar across devices. The exception was poorer performance at very high speech intensity levels (93 dB SPL) for the linear aid.

Moore and his colleagues (Laurence et al., 1983; Moore & Glasberg, 1986; Moore et al., 1985, 1992) worked extensively with an amplification system that applies a first stage, slow acting compression with a compression threshold of 75 dB SPL to compensate for overall level variations, followed by fast-acting compression amplifiers, acting independently in two frequency channels. The results showed improved speech reception threshold in quiet and in noise (Moore, 1987) and improved speech intelligibility, particularly at low input levels (Moore & Glasberg, 1986; Laurence et al., 1983) when compared to linear amplification or to slow-acting compression.

Evidence shows that individuals with hearing impairment demonstrate marked reduction in speech recognition scores in the presence of noise compared to individuals having normal hearing (Cohen & Keith, 1976; Leshowitz, 1977). This study attempted to determine whether word recognition scores obtained in noise were more sensitive to the presence of a hearing loss than recognition scores obtained in quiet. Subjects with normal hearing, high-frequency cochlear hearing loss, and flat cochlear hearing loss were tested in quiet and in the presence of a 500-Hz low-pass noise. Two signal-to-noise ratio conditions (SNRs) were employed, −4 dB and −12 dB. Words were presented at 40 dB SL (re: PTA) in one experiment and at 96 dB SPL for subjects with normal hearing in a second experiment. When the speech and noise were presented at high SPLs, however, the subjects with normal hearing had poorer word recognition than those with flat cochlear losses. The results are interpreted as indicating greater spread of masking in normalhearing than those with hearing impairment at high sound pressure levels.

It has been often reported that listeners with normal low frequency and selective high frequency hearing loss often experience great difficulties in perceiving speech in noise (Curtois, 1975), specifically, listeners with an abrupt high frequency loss due to noise trauma as well as the presbycusic individuals characterized by a more gradually sloping audiogram are the two major categories of the hearing impairmentthought to be especially vulnerable to noise (Leschowitz, 1977).

Yund and Buckles (1995) did a study to see the effect of number of channels on speech discrimination in the presence of noise by using four, six, eight, twelve and sixteen independent frequency channels. The SNR was varied from -5 to 15 dB with speech spectrum noise of 70 dB SPL. Average speech discrimination in the presence of noise for 16 subjects with hearing impairment increased from four to eight channels but there was no significant improvement from eight to sixteen channel hearing aids. The effect of number of channels did not vary significantly with the signal to noise ratio.

2.3 Effect of ChannelFree^{TM} processing on speech identification in quiet and in noise

The ChannelFree^{TM} hearing aid processing technology is a core technique unique to a particular hearing aid cimpany based on patented signal processing methods. It is claimed that ChannelFree^{TM} processing is unique due to several features of its technology such as instantaneous response to sound events, use of wideband SPL, measuring and filtering as parallel process and continues frequency response and filter adjustments.

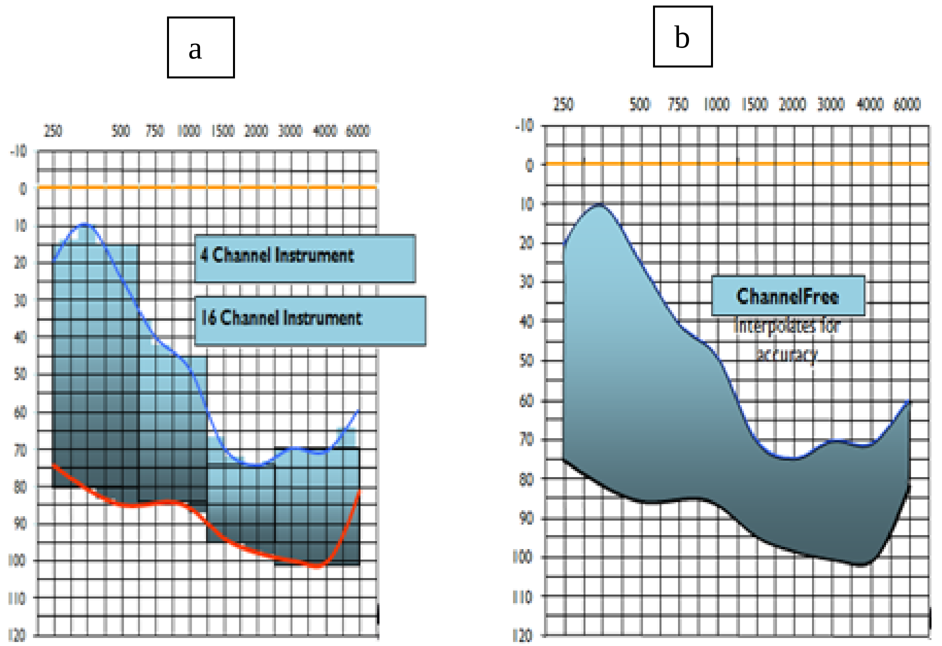

Figure 2.1 (a) Multichannel amplification error (b) ChannelFree™ precision

Schaub has reported that the ChannelFree™ uses a sophisticated algorithm to suppress ripple, while still tracking the level difference of consecutive phonemes in speech. ChannelFree therefore time-aligns the acoustic signal and the gain is applied. Multichannel compression, in particular fast-acting compression, systematically flattens the spectrum of any sound it processes. ChannelFree™ avoids multichannel compression and instead it preserves spectral contrast by using wideband SPL. It also incorporates several techniques to produce compression at 2 ms attack and 10 ms release time, while avoiding distortion. The major drawback of the multichannel hearing aid as reported by Stone et al. (2008) is the throughput delay which is the time span between the two events: 1) the moment when the microphone picks up a sound, and 2) the moment when the receiver emits the same amplified sound. This delay is most significant in avoiding distortion. As the delay is increased, perceptual error increased as found by Stone & his colleaugues with the delay time being 4 ms to 12 ms. In order to overcome this error, ChannelFree™ hearing aid technology uses lesser throughput delay of about 2.5 ms by exhibiting parallel processing, i.e., SPL measurement and amplification proceed simultaneously.

In terms of frequency resolution, the manufacturer's claims that ChannelFree™ processing is completely different from the early single-channel compression systems, which provided constant compression characteristics across all frequencies. ChannelFree™ processing allows independent adjustment of amplification at any frequency. In hearing aid fitting software, gain and compression characteristics can be adjusted at any standard audiometric frequency. This allows the amplification to be precisely tailored to the hearing loss. There is another important difference to multi-channel systems. It is also said that, in a channel-based system, the gain can be adjusted for each channel, but within the channel, the gain remains fixed that leads to a "stair step" effect in the frequency response, especially if the gain requirement is changing significantly across frequency. In contrast, ChannelFree™ processing is said to be interpolating across frequency smoothly, providing the highest quality sound experience.

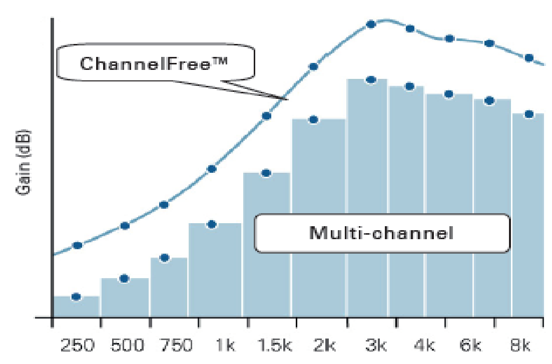

Figure 2.2 Comparison of frequency resolution in channelFree and multichannel processing.

This unique processing strategy satisfies the frequency-specific compressive requirements of sensorineural hearing loss, while retaining the intra signal spectral contrasts important for formant, phoneme and speech recognition. Continuously adaptive speech integrity (CASI) offers unique frequency shaping for optimal hearing loss appropriate frequency response curves. In addition, this unified signal processing occurs perceptually instantaneously, with appropriate gain characteristics calculated and applied to each incoming signal. CASI analyses incoming signals according to their intensity and dominant spectral elements, and calculates the corresponding gain characteristic to be applied. Spectral characteristics of speech are maintained resulting in more ‘natural’ sounding amplification. Additionally, because CASI maintains the natural signal structure, adaptation time may be less for the patient using CASI than for those using more typical multi-channel amplification (Yund & Buckles, 1995).

Schaub (2008) reported that the working principle of ChannelFree™ hearing aids that closely resembles cochlear non-linearity by providing a higher gain to low level signal and compressing a high level signal. One distinctive feature of channelFree processing is an extremely short reaction time of 10 ms, such short reaction time can cause distortion problem in conventional compression systems (Schaub, 2010).

Kumar (2007) studied comparison between multichannel and channelFree hearing aids in individuals with sloping SNHL with the age range between 35 and 60 years, with the mean age of 48.5 years. The participants performed better with ChannelFree hearing aids in quiet and in noise with constant SNR (+10 dB & 0 dB SNR) when compared to single channel and multichannel (4 and 8) hearing aids. The performance was better in 8-

channel hearing aid over three and single channel hearing aid only in noisy conditions. In his study, the hearing aids chosen were from different companies. Here, the hearing aids chosen for the experiment differs in companies which in turn might differ in technology made used in those hearing aids. The researcher has tried to account for speech intelligibility in both quiet and in the presence of noise but information on the quality of speech signal as perceived by the participants could have been added more valid onformation which has been incorporated in the present study.

Plyer et al. (2013) reported better speech scores for those individuals using open fit canal hearing aids. He compared between multichannel and channelFree processing using open canal fit hearing aids for the subjects with mild sloping to moderately severe sensorineural hearing loss (mean age of 67 years). The effectiveness was studied by providing the hearing aids for two weeks on a trial basis for all participants in the study. They concluded that Multichannel WDRC and ChannelFree processing are both effective signal processing strategies that provide significant benefit for hearing instrument users. Overall preference between the strategies may be related to the degree of hearing loss of the user, high-frequency in-situ levels, and/or acceptance of background noise. This study has accounted for similar benefits from both multi channel hearing aids and ChannelFree[TM] technology in older adult population with open fit canal hearing aids and differing only in terms of degree of hearing loss.

A recent study has revealed that ChannelFree[TM] hearing aids to be better when compared with regular multichannel hearing aids on speech identification performance for individuals with sloping sensorineural hearing loss(Hemanth et al., 2016). The main objective was to document consonant identification scores (CIS) and sequential transfer of information from multichannel and ChannelFree^{TM} hearing aids, in noise for those participants having bilateral sloping SNHL in the age range from 50 to70 years using syllables as test stimuli at quiet, +10 dB SNR and 0 dB SNR. It was observed that signal processing strategies did not significantly affect consonant identification on quiet condition. At +10 dBSNR and 0 dBSNR, significantly higher CIS was noted in ChannelFree^{TM} hearing aid than other multichannel hearing aids. In addition, the total sequential transfer of information transmitted from ChannelFree^{TM} hearing aid was higher than other strategies at quiet and +10 dB SNR. The study concluded saying that ChannelFree^{TM} hearing aid is a feasible alternative to multichannel hearing aids for listeners with sloping audiometric contours. The experiment has accounted only for the phonemic level performance in quiet and in noisy conditions. To extrapolate to real life situation, word level performance would have given better idea about ChannelFree^{TM} processing technology.

The influence of multichannel and ChannelFree^{TM} processing technology has been studied on vocal parameters in individuals with hearing impairment (Kodiyath, Mohan, & Bellur, 2017). The comparison was between the multichannel hearing aid and ChannelFree^{TM} hearing aid with noise reduction strategy on-off condition in the presence of noise to check for the comodulated masking release and uncomodulated masking release. The data were collected from 33 clients with sensorineural hearing loss, unilateral and bilateral with mild to moderately severe hearing impairment. The participants were both first time users and experienced hearing aid users with the age range from 18 to 75 years. One multichannel and one ChannelFree™ hearing aid of the same company were used for their experiment which is a positive factor. Target stimuli of 1000 Hz was used and 250 Hz, 500 Hz, 2000 Hz, and 4000 Hz were used as competing stimuli. The results revealed that subjects performed superior with the ChannelFree™ hearing aid with noise reduction on due to faster processing of incoming signal in order to retain the spectral contrast and also facilitate temporal cues from the amplified speech in noise. This study had a drawback of wide age range of participants by considering older adult population along with young adults. Studies have reported that the underlying mechanism for aging in sensorineural hearing loss is much more complex (Schuknecht, 1964). The study did not account for effect of neural degenerations due to aging on performance with multichannel and ChannelFree™ hearing aids. In addition, the participants' experiencewith hearing aid was also not controlled. This made it difficult to generalize the effectiveness of ChannelFree™ processing technique among all the sensorineural hearing.

The benefit from ChannelFree™ does not restrict only cochlear pathologies. Research done by Prabhu and Barman (2017) on the effectiveness of low-cut modified amplification strategy and ChannelFree™ hearing aid in individuals with auditory neuropathy spectrum disorder found that ChannelFree™ hearing aid with low cut modified amplifications as an effective alternative technique during hearing aid fitting in individuals with auditory neuropathy spectrum disorder (ANSD). The experiment was carried out with the sample size of 25 individuals with ANSD in the age range from 17 to 40 years (mean age 24.6 years). The stimuli used to obtain the speech identification scores were bisyllabic words assessed in quiet condition They compared between four channel hearing aid and a

ChannelFree™ hearing aid from different companies. Since the comparison of hearing aids did not take place within same company, this factor is a limitation of the study.

To summarize, ChannelFree™ hearing aid processing has been beneficial for those individuals with sensorineural hearing loss in quiet and in noise conditions and to those individuals with ANSD in quiet condition. At the end, the major factor to be applicable in real life situation is the quality output from the hearing device provided for those individuals. Quality rating for the speech signal has not been documented in the literature and also the amount of SNR required for a ChannelFree™ hearing aid processing has not been found out.

Chapter 3

Method

The main aim of the study was to compare the effect of ChannelFree^{TM} processing and multichannel processing in digital BTE hearing aid, in individuals with flat and sloping configurations of sensorineural hearing loss (SNHL). The objectives of the present study which included comparison of multichannel and ChannelFree^{TM} hearing aids on speech identification scores, SNR50, and quality in individuals with moderate flat SNHL and sloping SNHL. The details of the method in order to realize these objectives of the study are given below. The research design adopted for the present study was within and between group designs.

3.1 Participants

The age range of the participants was from 30 to 60 years (mean age of 45 years). The participants had post-lingual acquired hearing loss and were native speakers of Kannada language (a Dravidian language spoken in the state of Karnataka, India). The data were collected from 11ears with flat sensorineural hearing loss (Group I) and 10 ears with sloping sensorineural hearing loss (Group II). The participants in the study satisfied the following inclusion criteria:

- Group I comprised of 11 ears with flat configuration of audiogram. Flat configuration is operationally defined as audiometric thresholds across frequencies not varying by more than 20 dB from each other (Pittman & Stelmachowicz, 2003).

- Group II comprised of 10 ears with sloping audiogram configuration, with audiometric thresholds at equal or successively higher levels from 250 to 8000 Hz. The difference between thresholds at 250 and 8000 Hz was always >20 dB (Pittman & Stelmachowicz, 2003).
- Individuals with speech identification scores (SIS) greater than 60% in quiet in the test ear were considered. Individuals with bilateral SIS of >60% or the SIS in the better ear of >60% in case of asymmetrical hearing loss on routine audiological evaluations, were considered. In case of asymmetrical, hearing loss, the better ear was considered as the test ear.
- Test ears having 'A' type tympanogram either with acoustic reflexes present or absent.

3.1.2 Exclusion criteria : Following conditions are considered for exclusion of the participants

1. Individuals with any outer and middle ear infections.
2. Individuals with complaint of any cognitive related disorders.
3. Individuals with retro cochlear pathologies.
4. Those individuals having tinnitus and / or vestibular problems.

3.2 Material:

Recorded phonemically balanced (PB) test material in Kannada (Manjula, Geetha, Kumar, and Antony, 2014) consisting of 20 lists of Kannada bi-syllabic words was used. Out of this, six lists were used to obtain the SIS scores for ChannelFree^{TM} and multichannel hearing aid performances. The speech material used for the measurement of quality rating were three recorded passages in Kannada (Savithri & Jayaram, 2005) and one recorded passage (Sairam & Manjula, 2002), which were spoken with normal vocal effort by a native female speaker of Kannada. For the quality rating of five parameters including loudness, clearness, fullness, naturalness and overall impression, a 10-point rating scale was used (Hrishikesan 2009). Kannada four-speaker multi talker babble developed by Kumar (2012) was used to obtain SNR-50 for all the participants as a part of the study objectives. During speech audiometry, paired-word list in Kannada, developed in the Department of Audiology, AIISH, Mysore was used to obtain SRT values; and phonemically balanced test material in Kannada (Yathiraj & Vijayalakshmi, 2005) was used to obtain SIS scores. , During programming of the selected/test digital hearing aids for the participants, Ling's six sounds - /a/, /i/, /u/, /sh/, /s/, and /m/ was used to ensure the comfort and accurate listening.

3.3 Equipment:

A calibrated sound field audiometer was used to perform routine hearing evaluation, and to collect the unaided and aided data for the study. To route the recorded speech stimulus and passages for testing, audiometer loudspeakers kept at 0^0 Azimuth and at 1-meter distance were made used. A calibrated immittance meter was used to ensure normal middle ear functioning of all the participants included in the study. Three different digital BTE hearing aids were considered as the test hearing aids, viz., ChannelFree™ and two multichannel hearing aids (one with three channels and one with five channels). It was ensured that the fitting range of the test hearing aids ranged from mild to severe hearing loss in order to fit the hearing loss of the test ears. The two multi-channel hearing aids with similar technical specifications and the same manufacturer as that of ChannelFree™ hearing aid were selected. To program the hearing aids, NOAH software and hearing aid specific software with HiPro connected to a PC was made used of.

3.3.1 Programming of Hearing aids: The air-conduction and bone-conduction hearing thresholds of the test ear of the participant were fed into the NOAH software. The hearing aid software for programming the test hearing aid models was chosen. The test hearing aid was connected to the PC through a programming interface. The test hearing aid was programmed according to the audiogram and NAL-NL1 prescription, with client experience level set at ‘Novice’. The program mode for all the three hearing aids was set to multi environment listening and was utilized for data collection. Required adjustments were done to ensure the audibility of Ling's six sounds.

3.4 Test Environment:

Air-conditioned sound treated single/double room was made used to perform the testing.

3.5 Procedure:

The following procedure was followed in order to achieve the objectives of the study. The testing was done in three phases:

Phase I: Routine audiological evaluation to ensure participant selection criteria

Phase II: Aided speech identification in quiet

Phase III: Aided signal to noise ratios required for 50% performance (*SNR-50*)

3.5.1 Phase I: Routine audiological evaluation: In order to ensure the audiological inclusion criteria of the participants, audiometric air-conduction hearing thresholds were obtained at octave frequencies from 250 Hz to 8000 Hz for the test ear using modified Hughson-Westlake procedure (Carhart & Jerger, 1959). The bone-conduction thresholds were established at octave frequencies from 250 to 4000 Hz.

The speech recognition threshold (SRT), using the paired words in Kannada, was established by using a starting presentation level of 20 dB SL (re. pure tone average, PTA) (Tillman & Olsen, 1973). The speech identification score (SIS) was obtained at 40 dB SL (re: SRT) using the PB word list in Kannada (Yathiraj & Vijayalakshmi, 2005). The uncomfortable level (UCL) for speech in the test ear of the individual was also noted. The test stimuli were routed through the auxiliary input of the audiometer through headphones to the participant. Based on the audiometric results, the test ears were grouped as moderate flat SNHL or sloping configuration of SNHL. Immittance evaluation was done to rule out any middle ear pathology in the test ear.

3.5.2 Phase II: Aided speech identification in quiet: Selected hearing aids, viz., one ChannelFree^{TM} and two multichannel hearing aids (3-channel & 5-channel) were programmed. In quiet condition, one hearing aid of the three hearing aids chosen was selected to determine speech identification in quiet, using phonemically balanced word list in Kannada and presented to the participant. The participant was instructed to repeat the words heard. The aided SIS scores were obtained in each of the three aided conditions. The speech identification scores were obtained at 45 dB HL using the PB word list in Kannada (Manjula et al., 2014). The order of testing with the three hearing aids was randomized for each test ear.

3.5.3 Phase III: Aided response in noise (SNR-50): The level of speech, through audiometric loudspeaker was kept constant at 45 dB HL. The initial level of Kannada four-speaker multi talker babble through the same loud speaker was kept 15 dB HL below that of the speech i.e., at 30 dB HL. The level of the babble was increased in 5 dB steps, until the participant repeated at least two out of four (i.e., 50 %) words being presented. From this level, the speech babble was varied in 2 dB steps in order to obtain a more precise level of multi talker babble at which 50 % of the words were correctly repeated. At this instance, the difference in level of speech and multi talker babble was noted as the SNR-50 measure. This method was carried out for all three hearing aids selected.

3.6 Quality judgement

As a qualitative measure, a quality rating scale adapted by Sruthy and Manjula (2009) was used by presenting three different recorded paragraphs to each chosen hearing aid. The quality rating was based on five parameters and was 10-point rating scale, in which each parameter was designated with a range of two points of 10 point rating. It was administered to do the quality judgements of the recorded speech paragraphs chosen while listening through each of the three hearing aids chosen for the participant.

The parameters for quality rating and their point rating are as follows:

- Loudness with a rating scale from 0 to 10
- Clearness with a rating scale from 0 to 10
- Fullness with a rating scale from 0 to 10
- Naturalness with a rating scale from 0 to 10
- Overall impression with a rating scale from 0 to 10.

For each parameter, the rating varies from very poor to excellent with Very poor i.e., 0; Poor i.e., 0-2; Fair i.e., 2-4; Good i.e., 4-6; Very good i.e., 6-8; and Excellent i.e., 8-10.

3.7 Reliability check

In order to do the test-retest reliability check, 60% of the test ears from flat SNHL and sloping SNHL groups were tested again following procedure used for Phase II and Phase III, within two weeks of the first evaluation. During programming of the hearing aids, programmed database of first time evaluation was reloaded of those particular participants. The aided SIS, SNR-50 and quality rating were measured following the procedure described earlier.

3.8 Statistical analyses

The data collected from each test ear were tabulated and analysed using Statistical Package for the Social Sciences (SPSS for windows, version 17) software. The following statistical analyses were used:

1. Tests of Normality – Shapiro Wilk's test
2. Descriptive statistics
3. Inferential statistics

3.8.1 Infential statistics: Following are the test carried out to fullfil the objectives of the study

1. Friedman's test for comparison of ChannelFree^{TM}, three-channel and five channel hearing aids within group on the three audiological measures. If a significant difference was indicated, Wilcoxon signed rank test was performed.

2. Mann Whitney U test was done for comparison of parameters between groups.
3. Cronbach's alpha test used to analyse the test-retest reliability of SIS in quiet and SNR-50 parameters in both flat SNHL and sloping SNHL groups.

Chapter 4

Results

The main aim of the present study was to compare the effect of ChannelFree™ processing with that of multichannel (two- and three- channel) processing in hearing aids in ears with sensorineural hearing loss having flat and sloping configurations. . The objectives of the study were:

1. To evaluate the performance on speech identification in quiet with ChannelFree™ hearing aids in individuals with flat SNHL and sloping SNHL.
2. To evaluate the performance on speech identification in quiet with multi channel hearing aids in individuals with flat SNHL and sloping SNHL.
3. To evaluate the performance on speech identification in noise using SNR-50, with ChannelFree™ hearing aids in individuals with flat SNHL and sloping SNHL.
4. To evaluate the performances on speech identification in noise using SNR-50, with multi channel hearing aids in individuals with flat SNHL and sloping SNHL.
5. To compare the speech perception in quiet with channel free and multi channel hearing aids between flat SNHL and sloping SNHL.
6. To compare the speech perception in noise with channel free and multi channel hearing aids between flat SNHL and sloping SNHL.
7. To evaluate the efficacy of ChannelFree™ and multi channel hearing aids on quality of speech in individuals with flat SNHL and sloping SNHL.

The data on SIS in quiet, SNR-50 and rating on quality parameters (loudness, clearness, fullness, naturalness, overall impression) from eleven ears with flat moderate sensorineural hearing loss and ten ears with sloping sensorineural hearing loss comprising of seven male and three female participants (mean age of males = 57.4 years and females = 50.6 years) were tabulated and subjected to statistical analyses. The data were analyzed using Statistical Package for the Social Sciences (SPSS for Windows, version 17) software. The following statistical analyses were carried out:

1. Shapiro-Wilk test of normality
2. Descriptive statistics
3. Inferential statistics
   3.1 Friedman's test was done for comparison of channelFree, three-channel and five-channel hearing aids within group. If a significant difference was indicated, Wilcoxon signed rank test was performed.
   3.2 Mann Whitney-U test was done for comparison of parameters between groups.
4. Cronbach's Alpha test was used to analyze test-retest reliability of SIS in quiet and SNR-50 parameters in flat SNHL and sloping SNHL groups.

The results are discussed under the following headings:

4.1 Test of Normality

4.2 Effect of hearing aid processing on speech identification in quiet within and between groups

4.2.1 Comparison of hearing aid processing in flat SNHL.

4.2.2 Comparison of hearing aid processing in sloping SNHL.

4.2.3 Comparison of hearing aid processing on speech identification in quiet between flat and sloping SNHL groups.

4.3 Effect of hearing aid processing on speech identification in noise within and between groups

4.3.1 Comparison of hearing aid processing in flat SNHL.

4.3.2 Comparison of hearing aid processing in sloping SNHL.

4.3.3 Comparison of hearing aid processing on speech identification in noise between groups.

4.4 Effect of hearing aid processing on quality judgements within and between groups

4.4.1 Comparison of hearing aid processing on quality parameters in flat SNHL

4.4.2 Comparison of hearing aid processing on quality parameters in sloping SNHL

4.4.3 Comparison of hearing aid processing on quality parameters between groups

4.1 Test of Normality

In order to examine if the data collected were following normal distribution, Shapiro-Wilk's test was performed. Aided SIS in quiet, SNR-50 and quality rating data in three aided conditions, from 21 ears (11 ears with flat SNHL and 10 ears with sloping SNHL) were subjected for Shapiro-Wilk's normality test. Prior to this, it was ensured that there were no significant outliers, and hence all the data were retained for analyses.On Shapiro-Wilk's test, majority of the data, as shown in Table 4.1, did not follow normal distribution. Since the majority of the data were not normally distributed, non-parametric statistical analyses were performed.

Table 4.1 ***Significance value (p) for SIS in quiet and SNR-50 for two groups of ears using Shapiro-Wilk's normality test***.

S. No.	Parameters	Hearing aid processing	Group	df	p
1.	SIS	with 3-channel	Flat	11	0.001*
			Sloping	10	0.698
		with 5-channel	Flat	11	0.003*
			Sloping	10	0.021*
		with channelFree	Flat	11	0.205
			Sloping	10	0.111
2.	SNR-50	with 3-channel	Flat	11	0.409
			Sloping	10	0.596
		with 5-channel	Flat	11	0.449
			Sloping	10	0.881
		with ChannelFree	Flat	11	0.238
			Sloping	10	0.022*

Note: * indicates p = <0.05

4.2 Effect of hearing aid processing on speech identification in quiet within and between flat and sloping SNHL groups:

The effect of three types of hearing aid processing, viz., three-channel, five-channel and channelFree processing on SIS in quiet, SNR-50, and quality parameters were analyzed.

4.2.1 Comparison of hearing aid processing in flat SNHL: As a part of statistical analysis, Table 4.2 gives the mean, median and standard deviation of SIS in quiet with three-channel, five-channel and channelFree hearing aids for both flat and sloping SNHL groups.

Table 4.2: ***Mean, Median and standard deviation (SD) of SIS in quiet with three types of hearing aid processing in ears with flat and sloping SNHL.***

Parameter	Hearing aid processing	Mean		Median		SD	
		Flat	Sloping	Flat	Sloping	Flat	Sloping
SIS (Max.=25)	with 3-channel	22.2	20.4	23	21	0.9	2.5
	with 5-channel	22.8	20.9	24	21.5	1.6	2.7
	with ChannelFree	22.5	20.9	23	21.5	1.03	2.02

The results revealed that the SIS with three different hearing aid processing were similar in terms of mean, median and SD. In order to know if the slight differences in SIS was significantly different, Friedman's test was performed between hearing aids, in flat SNHL and sloping SNHL groups. Table 4.3 depicts Chi-square (χ^2value and 'p' value within flat SNHL and sloping SNHL groups. These values confirmed that then type of processing in hearing aids did not make a significant difference ($p>0.05$) in each of the two groups.

Table 4.3 ***Significant difference (χ^2 & p) between SIS with three hearing aid processing in flat and sloping SNHL groups.***

Parameter	χ^2		Significance (p value)	
	Flat	Sloping	Flat	Sloping
SIS with 3-channel, 5-channel and ChannelFree™	1.05	1.60	0.592	0.449

4.2.2. Comparison of hearing aid processing on speech identification in quiet between groups: Mann-Whitney U test was performed to find out if any difference existed in aided SIS scores between flat SNHL and sloping SNHL groups. Table 4.4 shows Z score and ‘p’ value for SIS in quiet condition across hearing aids.

Table 4.4 ***Significant difference (Z & p) in SIS with three hearing aid processing between flat SNHL and sloping SNHL.***

Parameter	/Z/	Significance (p)
SIS with 3-channel	-1.99	0.046*
SIS with 5-channel	-1.99	0.047*
SIS with channelFree	-2.062	0.039*

Note: * $p<0.05$

The results revealed that there was a significant difference between the flat and sloping groups, with higher SIS scores in flat SNHL with all the three types of hearing aid processing compared to sloping SNHL groups.

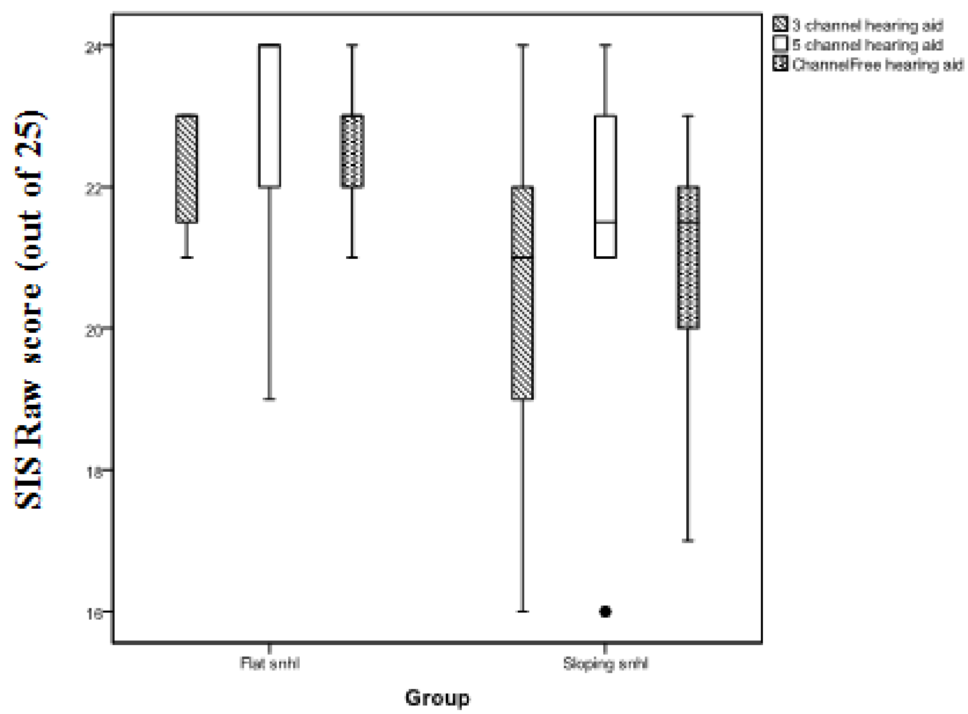

Figure 4.1 Box plot depicting the 95% CI of SIS scores (Max. 25) in two groups of participants

4.3 Effect of hearing aid processing on speech identification, in noise within and between groups:

The effect of three types of hearing aid processing, viz., three-channel, five-channel and channelFree processing on, SNR-50 was analyzed.

4.3.1 Comparison of hearing aid processing in Flat SNHL: Table 4.5 gives the mean, median, and standard deviation of SNR-50 for comparison of SNR-50 scores between 3-channel, 5-channel, and channelFree hearing aids within flat SNHL group.

Table 4.5 *Mean, median, and standard deviation (SD) of SNR-50 with three types of hearing aid processing in ears with flat and sloping SNHL*

Parameter	Mean		Median		SD	
	Flat	Sloping	Flat	Sloping	Flat	Sloping
SNR-50 with 3-channel	5.45	6.4	5	6	1.43	3.5
SNR-50 with 5-channel	4.81	6.5	5	6.5	1.16	2.27
SNR-50 with channelFree	3.45	5.4	3	4.5	1.29	2.5

The results revealed that the mean and median SNR-50 was lower with channelFree hearing aid compared to three-channel and five-channel hearing aids. That is the performance is better with channelFree hearing aid compared to the other two hearing aids.

Friedman's test was performed in order to find out if there was any difference in SNR-50 between hearing aids in flat SNHL group. Table 4.6 depicts chi-square (χ^2) values and 'p' values for flat SNHL and sloping SNHL groups. The results showed that the difference was significant between the hearing aids in flat SNHL group [χ^2 =10.585, p =0.005] and sloping SNHL group [χ^2 =8.909, p =0.012].

Table 4.6 ***Significant difference (χ^2 & p)on Friedman test for SNR-50 between three hearing aid processing for flat SNHL and sloping SNHL groups***

Parameter	χ^2		Significance (p)	
	Flat	Sloping	Flat	Sloping
SNR-50 with 3- channel SNR-50 with 5- channel SNR-50 with channelFree	10.585	8.909	0.005**	0.012*

Note: *: p<0.05, **: p<0.01

Since there was a significant difference between hearing aids in SNR-50 in flat SNHL group, Wilcoxon signed ranks test was performed to check the processing that was significantly different. Figure 4.7 depicts Z scores and 'p' values for paired conditions, i.e., between different hearing aid processing.

Table 4.7 ***Significant difference (Z & p) on Wilcoxon's test in SNR-50 between three hearing aid processing in flat SNHL and sloping SNHL***

SNR-50	/Z/		Significance (p)	
	Flat	Sloping	Flat	Sloping
Between 3-channel and 5-channel	1.30	0.96	0.191	0.339
Between 3-channel and channelFree	2.74	2.12	0.006**	0.034*
Between 5-channel and channelFree)	2.40	1.93	0.016*	0.054

Note: * p <0.05; **:p<0.01

The results reveal that there was no significant difference between three–channel and five-channel hearing aids in flat and sloping SNHL groups; and also between 5-channel and channelFree in sloping SNHL group. In all the other aided conditions, there was a significant difference in SNR-50.

4.3.2 Comparison of SNR-50 with different hearing aid processing in sloping SNHL: Table 4.5 gives the mean, median and standard deviation of SNR-50 for comparison of SNR-50 with 3-channel, 5-channel, and channelFree hearing aids in sloping SNHL group. The table shows that channelFree hearing aid has lower mean and median values for SNR-50 compared to three-channel and five-channel hearing aids.

Friedman's test was performed in order to check for the significant difference in SNR-50 between hearing aids in sloping SNHL group. Table 4.6 Depicts chi-square (χ^2) values and 'p' value for SNR-50 between hearing aid processing types within sloping SNHL group. The results showed that there is a significant difference between the hearing aids in SNR-50 parameter [$\chi^2 = 8.909$, $p = 0.012$]. Since there was a significant difference observed between hearing aids in SNR-50 in sloping SNHL group, Wilcoxon signed ranks test was performed in order to know the hearing aid processing that was bring about significantly different SNR-50. Figure 4.7 depicts Z score and 'p' value for difference in SNR-50 between three different hearing aids.

The results revealed that in sloping SNHL group, the channelFree hearing aid was significantly better than the three–channel hearing aid. (z = -2.124, p = 0.034). There was no significant difference between the other hearing aid processing conditions,.

4.3.3 Comparison of hearing aid processing on speech perception in noise between groups: Mann Whitney-U test was performed to find out if there was any difference in SNR-50 between flat SNHL and sloping SNHL groups. Table 4.8 shows Z score and ‘p’ value for SNR-50 with each hearing aid processing. The results revealed that there was no significant difference in SNR-50 between groups in three hearing aid processing conditions (p > 0.05).

Table 4.8. ***Significant difference (Z & p) in SNR-50 between flat SNHL and sloping SNHL with three different hearing aid processing.***

SNR-50	/Z/	Significance (p)
with 3-channel	0.42	0.670
with 5-channel	1.78	0.074
with channelFree	1.73	0.083

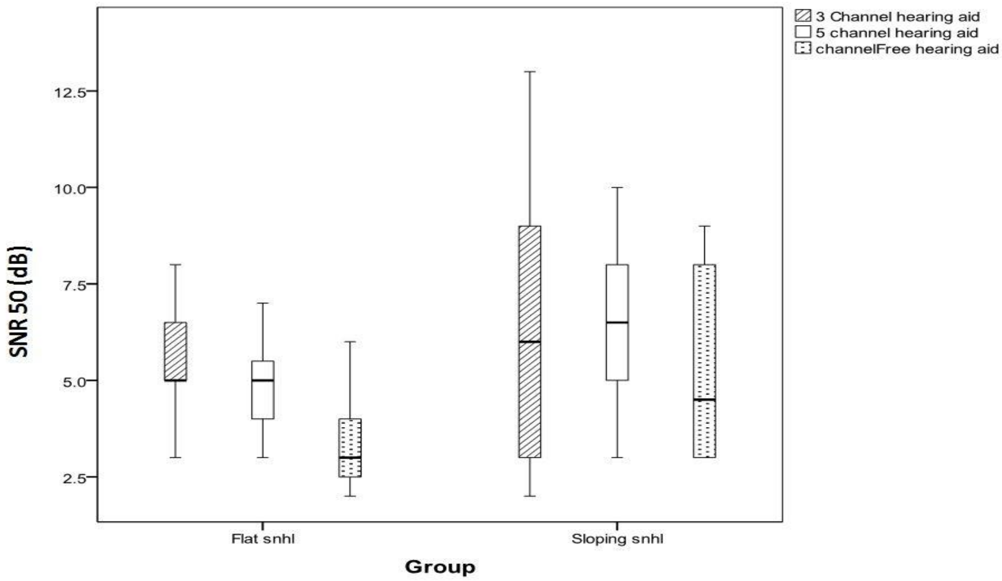

Figure 4.2: Box plot depicting the 95% CI of SNR-50 in flat and sloping SNHL groups.

From the Figure 4.2, it is evident that the SNR-50 is lowest in the ChannelFree^{TM} condition in both flat and sloping hearing loss groups.

4.3 Effect of hearing aid processing on quality judgements within and between flat and sloping SNHL groups:

The effect of three types of hearing aid processing, viz., three-channel, five-channel and channelFree^{TM} processing on, quality was analyzed.

4.3.1 Comparison of hearing aid processing on quality parameters in flat SNHL group: Table 4.9 shows the mean, median, and standard deviation for the parameters of quality rating in flat SNHL group and sloping SNHL group, on a rating scale of 0 to 10.

Table 4.9 ***Mean, median, and standard deviation (SD) of quality parameters with three hearing aid processing types in ears with flat and sloping SNHL.***

Quality Parameters	*Hearing aid processing*	*Mean*		*Median*		*SD*	
		Flat	*Sloping*	*Flat*	*Sloping*	*Flat*	*Sloping*
Loudness	3-Channel	6.18	5.6	6	6	0.60	1.26
	5-Channel	7.09	5.4	8	5	1.04	1.64
	ChannelFree	5.81	5.8	6	6	1.07	1.47
Clearness	3-Channel	4.18	4.8	4	4	0.60	1.39
	5-Channel	5.63	6.0	6	6	1.2	1.63
	ChannelFree	7.45	7.6	8	8	1.29	1.57
Fullness	3-Channel	5.45	6.2	6	6	1.2	1.13
	5-Channel	6.72	5.6	6	6	1.34	1.57
	ChannelFree	7.09	7.2	8	8	1.04	1.68

	3 Channel	5.27	5.6	6	6	1.34	1.57
Naturalness	5 Channel	5.81	5.8	6	6	1.07	1.75
	ChannelFree	7.81	7.0	8	7	1.40	1.69
Overall Impression	3 Channel	5.81	6.4	6	6	0.60	1.26
	5 Channel	7.09	6.4	8	6	1.04	1.57
	ChannelFree	8	7.8	8	8	0.00	1.98

From Table 4.9, it can be noted that the channelFree processing was rated to be better than the 3-channel and 5-channel processing in terms of clearness, fullness, naturalness and overall impression. This was true for flat and sloping SNHL groups. However, the loudness was rated to be higher with 5-channel hearing aid followed by 3-channel and channelFree hearing aids. In order to see if the hearing aid processing had a significant effect on each parameter of quality judgement in flat SNHL population, Friedman's test was performed.

In order to see the effect of hearing aid processing on each of the five parameters of quality judgement in flat SNHL and sloping SNHL population, Friedman's test was performed. Table 4.10 shows the chi-square value and 'p' value for all five parameters of quality between the hearing aid processing, in flat SNHL and sloping SNHL groups. The result shows significant difference between hearing aids in all the parameters in flat SNHL group . In case of sloping SNHL group, except for loudness parameter, all other four parameters showed a significant difference between hearing aid processing.

Table 4.10. *Significant difference (χ^2 & p) in quality judgement parameters between three hearing aid processing in flat SNHL and sloping SNHL groups.*

Parameter	*Hearing aid processing*	χ^2		*Significance (p)*	
		Flat	*Sloping*	*Flat*	*Sloping*
Loudness	With 3-Channel, 5–Channel, & ChannelFree	8.00	0.296	0.018*	0.862
Clearness	With 3-Channel, 5Channel, & ChannelFree	14.098	11.806	0.001**	0.003**
Fullness	With 3-Channel, 5–Channel, & ChannelFree	6.414	6.242	0.040*	0.044*
Naturalness	With 3-Channel, 5–Channel, & ChannelFree	9.75	7.032	0.008**	0.030*
Overall Impression	With 3-Channel, 5–Channel, & ChannelFree	16.545	6.750	0.000**	0.034*

Note: * p <0.05, **: p<0.01

The Wilcoxon's signed rank test was done to check hearing aid processing that significantly differed on all the five quality parameters. Table 4.10 depicts Z value and 'p' value for quality parameters between hearing aid processing conditions,separately in flat SNHL and sloping SNHL group. The results observed are as follows:

- Except for the loudness being significantly higher with 5-channel compared to channelFree condition, there was no significant difference between any of the aided conditions in flat SNHL group. In case of sloping SNHL, loudness did not differ between hearing aids.
- For clearness parameter, in all the three paired condition, ChannelFree^{TM} hearing aid processing tends to be much clearer than three channel and five channel hearing aids in flat SNHL group sloping SNHL.
- Except for the fullness being significantly higher with ChannelFree^{TM} compared to three channel hearing aid, there was no significant difference between any of the aided conditions in flat SNHL group. In case of sloping SNHL group, fullness being significantly higher with ChannelFree^{TM} compared to five channel hearing aid.
- For naturalness parameter, perception through ChannelFree^{TM} hearing aid processing was found to be more natural compared to three channel, there was no significant difference between any of the aided conditions in flat SNHL group and sloping SNHL group of population.
- Overall impression was better preferred with ChannelFree^{TM} hearing aid processing when compared to three channel and five channel, where significant difference between three channel and five channel hearing was not observed in flat SNHL group and sloping SNHL.

Table 4.11. ***Significant difference (Z & p) in quality judgement parameters between three hearing aid processing in both flat SNHL and sloping SNHL groups.***

Quality Parameter	*Hearing aid processing*	*/Z/*		*Significance (p)*	
		Flat	*Sloping*	*Flat*	*Sloping*
Loudness	3-channel & 5-channel	1.89	-	0.06	-
	3-channel & - ChannelFree	0.81	-	0.41	-
	5-channel & ChannelFree	2.33	-	0.02*	-
Clearness	3-channel -5-channel	2.31	1.50	0.02*	0.13
	3-channel & ChannelFree	2.97	2.72	0.00*	0.00*
	5-channel & ChannelFree	2.23	2.07	0.02*	0.03*
Fullness	3-channel -5-channel	1.93	1.00	0.05	0.31
	3-channel ChannelFree	2.16	1.50	0.03*	0.13
	5-channel & ChannelFree	0.70	2.39	0.48	0.02*
Naturalness	3-channel -5-channel	1.13	0.378	0.25	0.70
	3-channel & ChannelFree	2.45	2.33	0.01*	0.02*
	5-channel & ChannelFree	2.37	2.12	0.02*	0.03*
Overall Impression	3-channel -5-channel	2.34	0.00	0.02*	1.00
	3-channel ChannelFree	3.20	2.11	0.00*	0.03*
	5-channel & ChannelFree	2.23	2.11	0.02*	0.03*

Note: * : $p < 0.05$

4.3.2 Comparison of quality judgement parameters between groups: Mann-Whitney U test was performed to find out if there was any difference in quality judgement rating between flat SNHL and sloping SNHL groups. Table 4.11 shows Z score and 'p' values for quality ratings in each type of hearing aid processing. The loudness parameter was significantly higher in flat compared to sloping SNHL group [z = -2.367, p = 0.018].

Table 4.12 ***Significant difference (Z & p) in quality parameters in three hearing aid processing between flat and sloping SNHL groups.***

Quality Parameters	*Hearing aids*	*/Z/*	*Significance (p)*
Loudness	3–channel	-1.370	0.171
	5–channel	-2.367	0.018*
	ChannelFree	0.081	0.935
Clearness	3–channel	-1.236	0.217
	5–channel	0.381	0.703
	ChannelFree	0.081	0.935
Fullness	3-channel	-1.384	0.166
	5–channel	-1.658	0.097
	ChannelFree	0.275	0.783
Naturalness	3–channel	0.461	0.645
	5–channel	0.423	0.672

	ChannelFree	-1.143	0.253
Overall Impression	3–channel	-1.370	0.171
	5-channel	-1.477	0.140
	ChannelFree	0.000	1.000

Note: * : p <0.05

4.4 Test-retest reliability

In order to evaluate the reliability of the data, 60% of the ears of participants were subjected for re-test following the same procedure given in the chapter of Methods. The collected data were subjected to Cronbach's alpha analysis to check for internal consistency for the parameters such as SIS in quiet, SNR-50, and quality judgements for flat SNHL and sloping SNHL (Table 4.13).

Table 4.13 ***Test-retest reliability for SIS in quiet and SNR-50 in flat SNHL group.***

Parameters	*Hearing aid processing*	*Cronbach's α*	
		Flat	*Sloping*
SIS	With 3-channel	0.946	0.969
	With 5-Channel	0.968	0.984
	With channelFree	0.966	0.976
SNR-50	With 3-channel	0.828	0.973
	With 5-Channel	0.981	0.972
	With channelFree	0.906	0.992

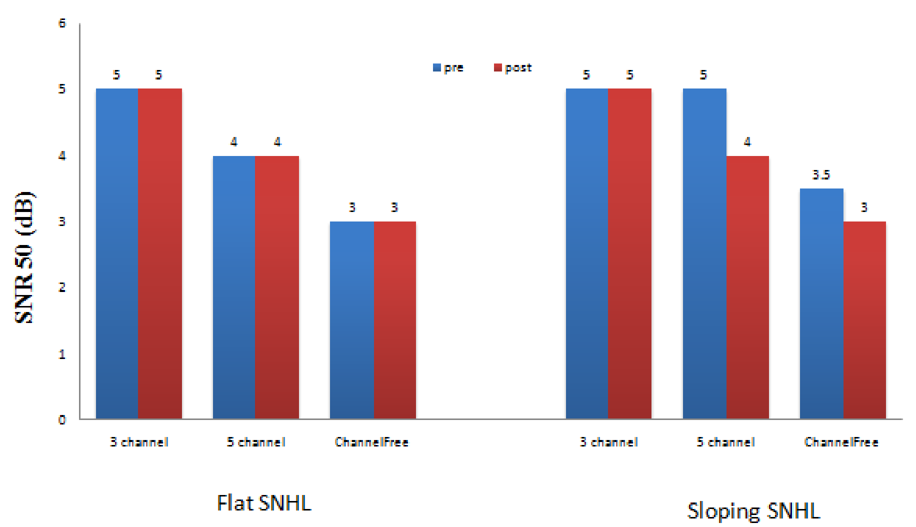

Figure 4.3 Test and re-test data on SNR-50 with three hearing aid processing types in flat and sloping SNHL groups

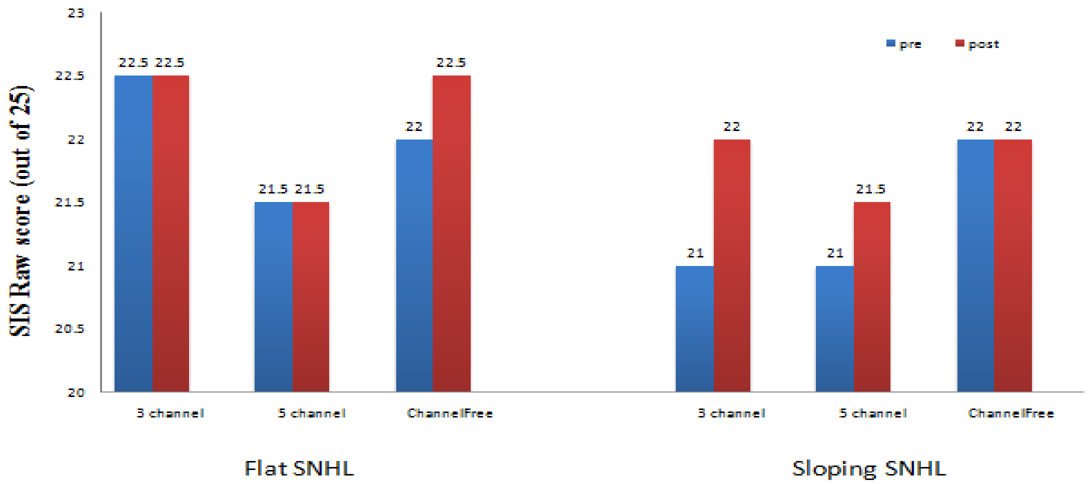

Figure 4.4 Test and re-test data on SIS with three hearing aid processing types in flat and sloping SNHL groups.

Table 4.14 ***Test-retest reliability Cronbach's alpha value for quality judgement parameters in flat SNHL and sloping SNHL***

Parameters	*Hearing aid processing*	*Cronbach's α*	
		Flat	*Sloping*
Loudness	With 3-channel	1.00	0.793
	With 5-Channel	1.00	1.00
	With channelFree	0.762	0.889
Clearness	With 3-channel	1.00	0.828
	With 5-Channel	0.762	0.880
	With channelFree	0.828	1.00
Fullness	With 3-channel	1.00	0.867
	With 5-Channel	1.00	0.726
	With channelFree	0.828	0.908
Naturalness	With 3-channel	0.833	0.892
	With 5-Channel	0.828	0.972
	With channelFree	1.00	0.960
Overall Impression	With 3-channel	0.828	0.828
	With 5-Channel	1.00	0.867
	With channelFree	1.00	0.881

The Cronbach's alpha values (Tables 4.11 & 4.12) indicated that the data in all the parameters were reliable (i.e., $\alpha > 0.70$), between the first and the second evaluations.

To conclude, among the three hearing aid processing strategies investigated, ChannelFree™ hearing aid processing was found to be a better option to perceive in the presence of noise and in terms of quality judgement compared to multichannel hearing aid processing for flat SNHL as well as sloping SNHL groups. Further, ChannelFree™ hearing aid processing is more beneficial in the presence of noise for flat SNHL group of population.

Figures 4.5, 4.6, 4.7, 4.8, 4.9, and 4.10 are the graphs showing the number of participants, of both flat and sloping SNHL, rating for different parameters of quality with three hearing aid processing.

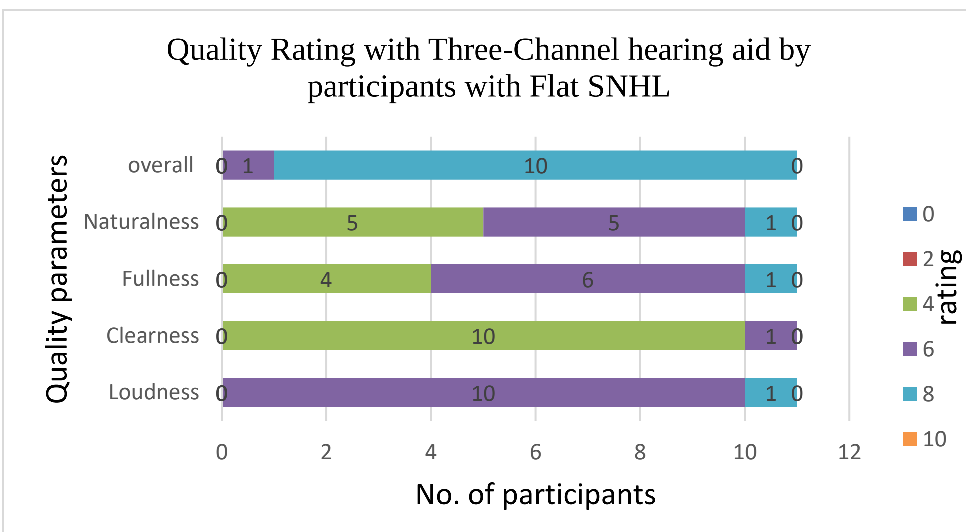

Figure 4.5 Number of participants of flat SNHL rated for each quality parameter with three channel hearing aid processing.

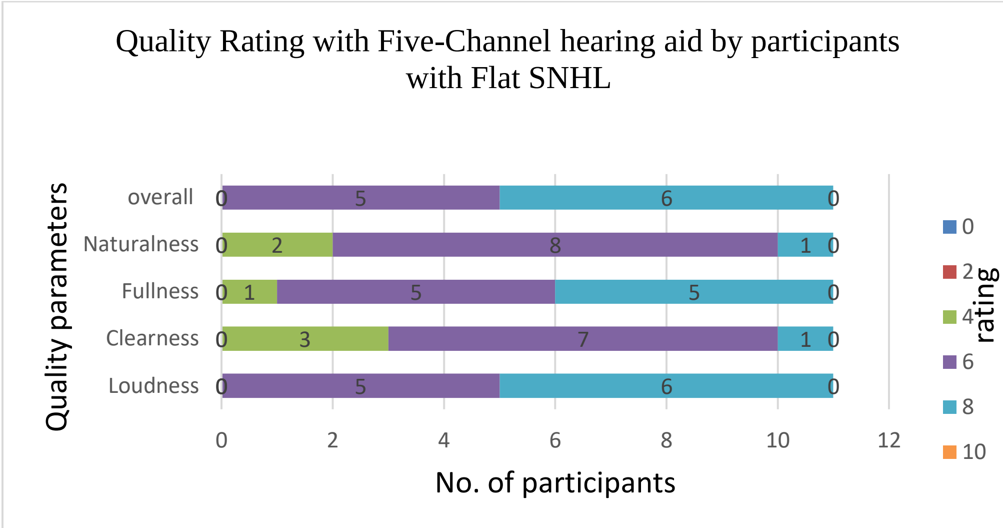

Figure 4.6 Number of participants of flat SNHL rated for each quality parameter with five channel hearing aid processing.

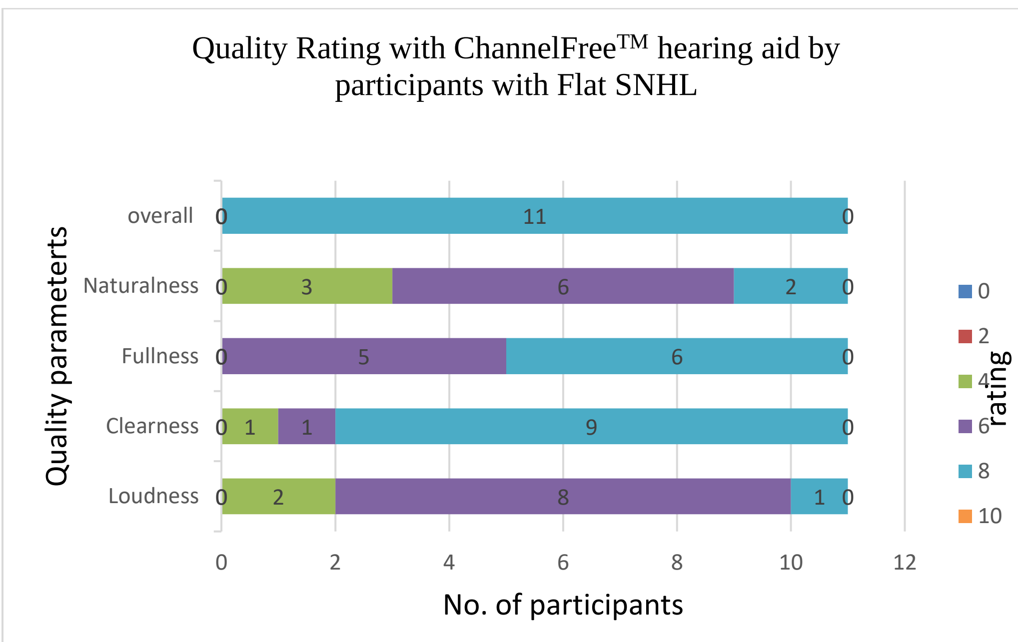

Figure 4.7 Number. of participants of flat SNHL rated for each quality parameter with ChannelFree™ hearing aid processing.

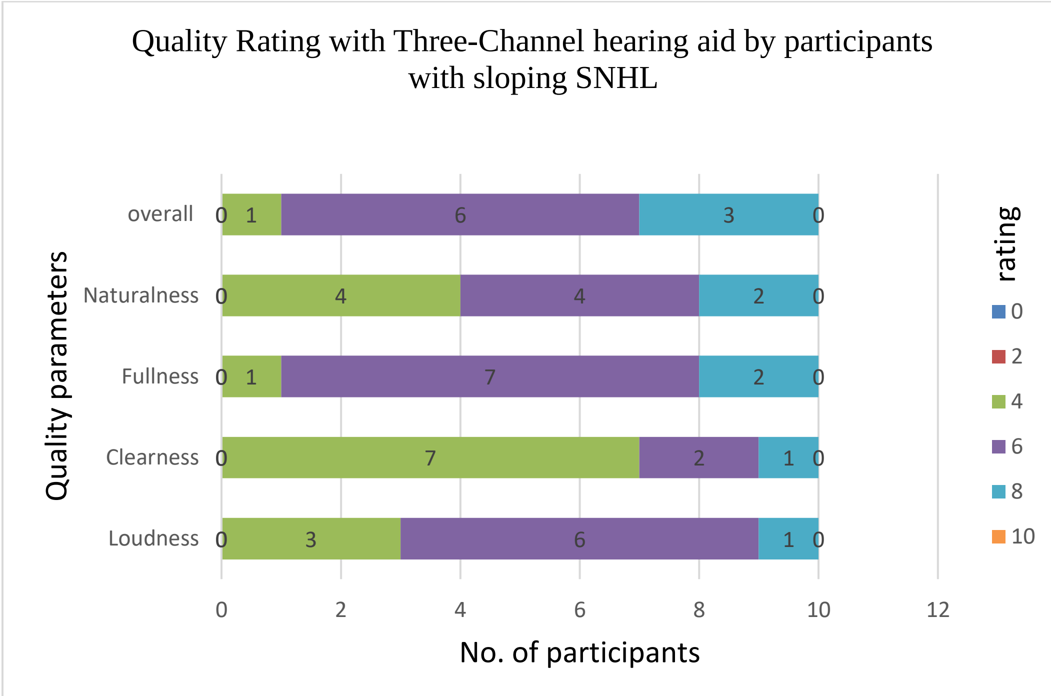

Figure 4.8 Number of participants of sloping SNHL rated for each quality parameter with three channel hearing aid processing.

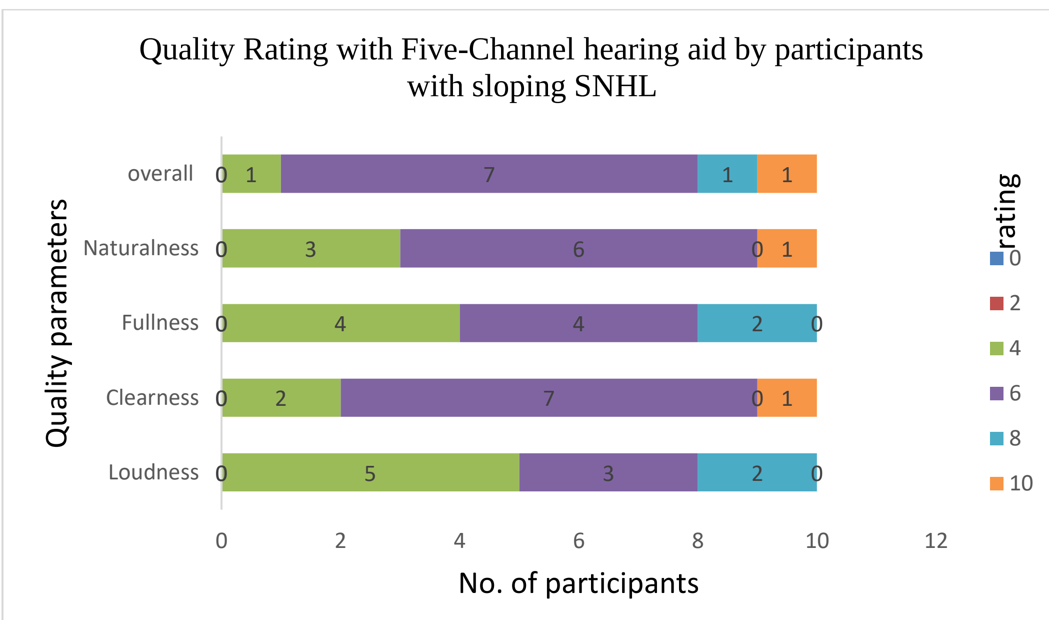

Figure 4.9 Number of participants of sloping SNHL rated for each quality parameter with five channel hearing aid processing.

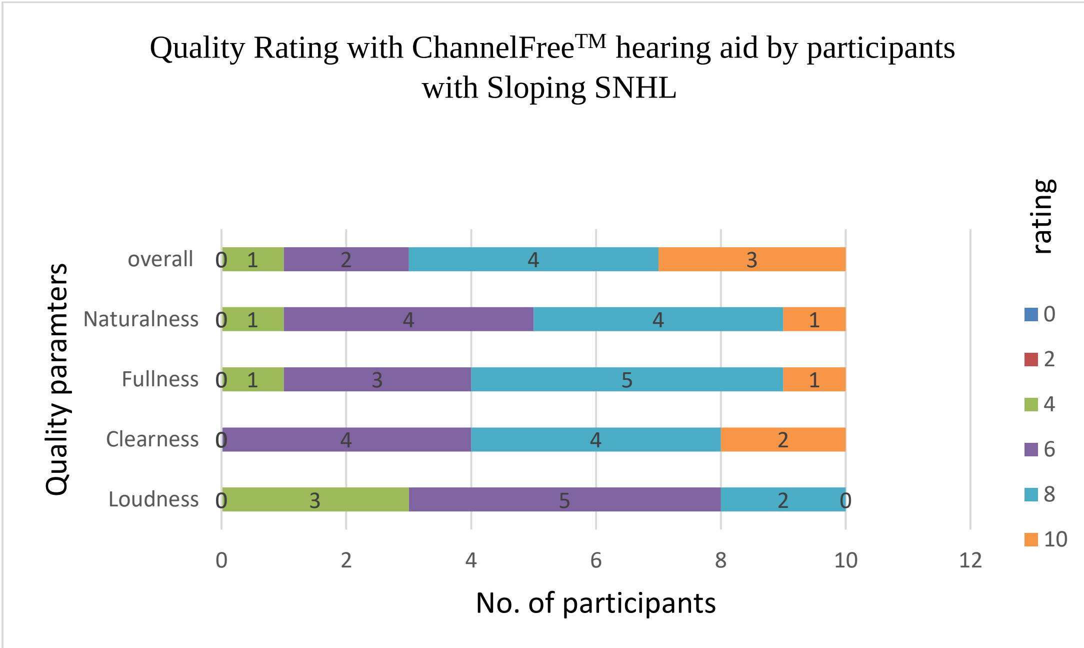

Figure 4.10 Number of participants of sloping SNHL rated for each quality parameter with ChannelFree™ hearing aid processing.

From the figures 4.5, 4.6, 4.7, 4.8, 4.9 & 4.10 for each parameter with three channel, five channel and ChannelFree™ hearing aids, the maximum rating can be inferred which is provided by flat and sloping SNHL group.

For loudness parameter, maximum rating provided out of ten is six with three - channel and with ChannelFree™ hearing aid from both the groups. With five - channel, flat group rated eight and sloping SNHL group rated four out of ten.

Clearness parameter has been rated with the maximum of four with three-channel hearing aid, six out of ten with five-channel hearing aid and eight out of ten with ChannelFree™ hearing aid from both the groups.

Fullness parameter has been rated maximum with six out ten with three-channel and five-channel hearing aid and rated maximum with eight out of ten with ChannelFree^{TM} hearing aid from both the groups.

For naturalness parameter, with three-channel, five-channel and ChannelFree^{TM} hearing aid, equal rating of four and six was given by flat SNHL group. Individuals with sloping SNHL rated maximum of four with three-channel, six with five-channel and equal rating of six and eight with ChannelFree^{TM} hearing aid processing.

Overall impression was rated maximum of eight with three-channel, five-channel and ChannelFree^{TM} hearing aid by flat SNHL group, whereas sloping SNHL group rated maximum of six with three-channel and five-channel hearing aid, and maximum of eight with ChannelFree^{TM} hearing aid processing.

Since the present study has comprised of many variables such as two groups of participants of flat and sloping SNHL, three different hearing aid processing of three channel, five channel and ChannelFree^{TM} hearing aids, and three different parameters of SIS, SNR-50 and quality rating (five parameters), it is summarized in Table 4.15 for better understanding of the test result findings.

Table 4.15 *Combined results of SIS, SNR-50, and quality parameters for flat and sloping SNHL with three hearing aid processing.*

Parameter	*Groups*	*Hearing aid processing*	*Significant difference*
SIS	Flat SNHL	5-channel > 3-channel = ChannelFree	Not significantly different (p>0.05)
	Sloping SNHL	ChannelFree = 5-channel > 3-channel	Not significantly different (p>0.05)
SNR-50	Flat SNHL	ChannelFree > 3-channel = 5-channel	1. ChannelFree > 3-channel (p<0.01) 2. ChannelFree > 5-channel (p<0.05) 3. 3-channel = 5-channel (p>0.05)
	Sloping SNHL	ChannelFree > 3-channel > 5-channel	1. ChannelFree > 3-channel (p<0.05) 2. 5-channel = ChannelFree™ (p>0.05) 3. 3-channel = 5-channel (p>0.05)
Quality a.Loudness	Flat SNHL	5-channel > 3-channel = ChannelFree	1. 5-channel > ChannelFree™ (p<0.05) 2. 3-Channel = ChannelFree™ (p>0.05) 3. 3-channel=5-channel (p>0.05)
	Sloping SNHL	3-channel = ChannelFree > 5-channel	Not significantly different (p>0.05)

b.Clearness	Flat SNHL	ChannelFree > 5-channel > 3-channel	1. ChannelFree™ > 5- Channel (p<0.05) 2. ChannelFree™ >3-Channel (p<0.05) 3. 5-channel > 3-channel (p<0.05)
	Sloping SNHL	ChannelFree > 5-channel >3-channel	1. ChannelFree™ >5-channel (p<0.05) 2. ChannelFree™ >3-Channel (p<0.01) 3. 3-channel=5-channel (p>0.05)
c.Fullness	Flat SNHL	ChannelFree > 3-channel = 5-channel	1. ChannelFree™> 3-Channel (p<0.05) 2. 3-channel=5-channel (p>0.05) 3. 5-channel=ChannelFree™ (p>0.05)
	Sloping SNHL	ChannelFree > 3-channel = 5-channel	1. 5-channel=ChannelFree™ (p>0.05) 2. 3-Channel=ChannelFree™ (p>0.05) 3. 3-channel=5-channel (p>0.05)
d.Naturalness	Flat SNHL	ChannelFree > 3-channel = 5-channel	1. 3-channel=5-channel (p>0.05) 2. ChannelFreeTM >5-channel (p<0.05) 3. ChannelFreeTM >3-Channel (p<0.05)
	Sloping SNHL	ChannelFree > 3-Channel= 5-channel	1. 3-channel=5-channel (p>0.05) 2. 5-channel=ChannelFree™ (p>0.05)

			3. 3-Channel=ChannelFree™ ($p>0.05$)
e.Overall impression	Flat SNHL	ChannelFree > 3-channel = 5-channel	1. 5-channel>3-channel ($p<0.05$) 2. 5-channel=ChannelFree™ ($p>0.05$) 3. ChannelFree™ > 3-Channel ($p<0.05$)
	Sloping SNHL	ChannelFree > 3-channel = 5-channel	1. 3-channel=5-channel($p>0.05$) 2. ChannelFree™ >5-channel ($p<0.05$) 3. ChannelFree™ >3-Channel ($p<0.05$)

These findings are discussed in the next chapter with reference to the earlier studies.

Chapter 5

Discussion

The objective of the study was to evaluate the performance of individuals with flat and sloping sensorineural hearing loss with channelFree and multichannel hearing aids. The data was tabulated according to three major objectives and is discussed in this chapter under different headings.

5.1. Speech intelligibility in quiet in flat and sloping SNHL groups.

5.2. Speech intelligibility in noise in flat and sloping SNHL groups.

5.3. Quality judgement in flat SNHL and sloping SNHL groups.

Speech identification scores in quiet, speech intelligibility in noise and speech quality judgement were used in order to know the effect of three-channel, five-channel and ChannelFree^{TM} processing technology in digital Behind-The-Ear hearing aids.

5.1. Speech intelligibility in quiet condition for flat and sloping SNHL groups.

The results for speech intelligibility in quiet for flat SNHL and sloping SNHL groups did not reveal any significant difference among the three hearing aids taken in this study. The performance for speech identification in quiet was similar across three-channel, five-channel and ChannelFree^{TM} hearing aids. It is noteworthy that the type of processing investigated in the study did not affect the performance in quiet. All these processing types brought about a significant improvement in performance. Probably, since the task of speech identification in quiet is relatively an easy task, the difference in the effect of type of processing was not evident.

In a study by Yund and Buckles (1995), it was reported that there was no difference for speech identification in quiet between 4-, 8- and 12- channel hearing aids. Irrespective of the number of channels, the performance remained similar in both flat and sloping SNHL, as was seen in the present study with 3- and 5- channels.

5.2. Speech intelligibility in noise in flat and sloping SNHL groups.

The results for SNR-50 as a measure of speech intelligibility in the presence of noise showed better performance with ChannelFree™ hearing aid compared to three-channel and five-channel hearing aids, in flat and sloping SNHL groups. This improvement could be because the ChannelFree™ processing adjusts the gain on an average of 20,000 times for each phoneme by measuring its sound pressure level in the level measurement block. This would facilitate the audibility within restricted dynamic range of participants with hearing impairment (DeSilva et al., 2016). In the study by Hemanth et al., 2016 the performance was measured with different SNRs i.e., at +10 dB SNR and 0 dB SNR. They found better speech intelligibility in noise irrespective of SNRs with channelFree processing compared to multichannel processing.. In addition, the channelFree hearing aid rapidly adjusts the gain with respect to the input signal. This scheme in ChannelFree™ hearing aid could compensate for the mechanism of the cochlea that is lost i.e, amplification of soft sounds and compressing loud sounds in presence of noise (Stelmachowicz et al., 1995).

The performance in the presence of noise remained similar with three-channel and five-channel hearing aids in the present study. Yund, Simon, and Efron (1987) have reported that the performance with multichannel hearing aids is poorer because of the speech distortions that are caused by the type of compression and time constants applied in different channels of a multichannel hearing aid. That is, when the input signal is broken into channels, and applying compression and fast time constants, the spectro temporal features become distorted and important information on speech transition is lost, which has been found to impair speech understanding (Boothroyd et al., 1996). In a later study by Yund and Buckles (1995), it has been reported that there is an improvement in performance in noise with the number of channels increasing up to eight.

The finding of better performance in noise with ChannelFree™ hearing aids compared to multichannel hearing aids in the present study could be because the ChannelFree™ hearing aid technology attempts to overcome the adverse effect of multichannel compression on spectral contrasts in speech. The ChannelFree™ hearing aid does not split the incoming speech signal into different channels, thereby ensuring that the hearing aid output retains the spectral contrasts present in the input speech (Prabhu & Barman, 2017).

For the superior performance by ChannelFree™ hearing aid, Kodiyath, Mohan and Bellur (2017) said that ChannelFree™ hearing aid strategies with noise reduction are able to process incoming signal faster in order to retain the spectral contrast and also facilitate temporal cues from the amplified speech in noise.

The results comparing between groups revealed that individuals with flat SNHL had better performance in noise compared to sloping SNHL. Researchers have said that high frequency information has a critical role in speech identification in the presence of background noise (Hornsby & Ricketts, 2003; Turner & Henry, 2002). This is in contrast to results from an earlier study using the same paradigm but completed in quiet (Hogan & Turner, 1998). The authors suggest that the difference in results obtained in quiet and in noise are due to differences in the relative access to "easy" i.e., voicing and manner cues and "more difficult" i.e., place of articulation speech cues when speech is presented in quiet versus noise backgrounds. Baer, Moore, and Kuk (2002) found that, in noise, persons with hearing loss and cochlear dead regions in the high frequencies were less able to make use of amplified high frequency speech information than persons with hearing loss but without dead regions.

5.3 Quality judgement in flat SNHL and sloping SNHL groups.

The results of the present study on quality judgements for five different parameters of quality in flat and sloping SNHL yielded similar findings. Out of the five parameters of quality rating, only loudness parameter varied between groups across hearing aids. It was found that the maximum rating obtained for loudness parameter in individuals with flat SNHL was eight through five-channel hearing aid, followed by three-channel and ChannelFree™ hearing aid. Whereas, in individuals with sloping SNHL, loudness parameter was rated comparatively lower through five-channel hearing aid. Other parameters like clearness, fullness, naturalness and overall intelligibility impression were rated significantly better through channelFree hearing aid compared to three-channel and five-channel hearing aids by flat SNHL and sloping SNHL .In contrast with this result, a study has shown that the performance based on quality rating remains similar between ChannelFree™ and seven-channel hearing aid for individuals with SNHL in quiet as well as in noisy situations (Plyer et al., 2013).

From the present study, it can be inferred that participants of both groups are benefitted from ChannelFree™ processing and are subjectively satisfied with the quality of amplified speech signal. The reason for better quality transmitted through ChannelFree™ processing could be lower distortion.

Chapter 6

Summary and Conclusion

The present study aimed to compare the performance of three-channel, five-channel and ChannelFree^{TM} hearing aid processing in individuals with flat SNHL and sloping SNHL. The study was conducted on eleven ears of participants with flat SNHL (Group I) and ten ears of participants with sloping SNHL (Group II). Routine audiological tests were performed to ensure participant fulfilment of participant selection criteria. Data on speech identification scores for high frequency word lists, SNR-50 and quality rating were tabulated for each test ear with each of the three hearing aid processing strategies. Descriptive statistics and inferential statistics were carried out using SPSS software (v 17 for Windows). The findings are summarized in the following sections.

6.1 Speech identification in quiet

- ✓ The median SIS was higher with 5-channel followed by 3-channel and channelFree processing.
- ✓ There was no significant difference between the three hearing aids, for the flat as well as sloping SNHL groups.
- ✓ The SIS of the flat SNHL was significantly higher than SIS of the sloping SNHL group. This was true for each of the three types of hearing aid processing.

6.2 Speech intelligibility in noise

- ✓ The performance with ChannelFree^{TM} processing is higher than three-channel and five-channel hearing aid processing, for flat and sloping SNHL groups.
- ✓ In flat SNHL group, the performance was significantly better with ChannelFree^{TM} compared to 3-channel and 5-channel processing.
- ✓ In sloping SNHL, performance with ChannelFree^{TM} was significantly better than 3-channel and 5-channel processing. However, the 3-channel and 5-channel were not significantly different in performance.
- ✓ The performance was not significantly different between the flat and SNHL groups in each of the three types of hearing aid processing.

6.3 Quality judgement

- ✓ The results revealed that all the parameters of quality (such as clearness, fullness, naturalness, and overall impression) were rated superior with channelFree processing compared to 3-channel and 5-channel processing, except for loudness which was rated to be louder with 5-channel processing.
- ✓ In flat SNHL, the overall impression was better with channelFree and 5-channel processing compared to 3-channel processing.
- ✓ In sloping SNHL, the overall impression was better with channelFree compared to 5-chanel and 3-channel processing.

To summarize, the three types of hearing aid processing bring about comparable performance for speech identification in quiet. For speech identification in noise, the performance was better with ChannelFree^{TM} processing than 3-channel and 5-channel. For ajority of parameters of quality, the ChannelFree processing was superior than the 3-channel and 5-channel processing. These findings were true for flat as well as sloping configurations of SNHL.

The ChannelFree processing is found to be better in terms of speech intelligibility as well as in quality. This aspect will contribute in longer durations of hearing aid usage and improved quality of life in individuals with SNHL.

6.4 Clinical implications

- ✓ ChannelFree™ hearing aid processing can be recommended to those individuals with SNHL of flat and sloping configurations, as it was documented in the study that the performance was better than the multichannel hearing aids.

6.5 Future directions

- ➢ The study was conducted in adult population. Further, study can be conducted on older adult populations to check for the benefit of ChannelFree™ hearing aid processing in those individuals with neural degeneration.
- ➢ The sample size taken was less. Further, to take up more participants to make the test findings more valid.
- ➢ The effect of using other types of speech stimuli (viz., monosyllables, sentences) can be investigated.

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