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Profiling outcomes in clients with bimodal hearing

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ABSTRACT

The current study aims to profile the outcome measures of bimodal hearing in terms of speech perception in noise, pitch pattern differentiation ability and also the range of hearing disabilities across several domains using the Speech, Spatial and Qualities of Hearing Scale (SSQ). A total of 15 subjects with age range of 6 – 20 years have participated in the study. Primarily aided responses were obtained for frequencies ranging from 250Hz to 8 KHz under three conditions. Loudness scaling procedure was attempted to obtain the most comfortable level. At the level of MCL, Pitch pattern test scores and also speech perception in noise scores by using variable SNR procedure were obtained under three conditions along with SSQ questionnaire administration. The results of the speech perception in noise test reveal that subjects with bimodal stimulation have shown a mean of +4 dB SNR improvement in signal to noise ratio when compared with CI alone condition. The temporal organization capacity is also better with bimodal condition with a mean percentage of 58.4% when compared with the unimodal condition. The perceptual rating of the bimodal condition also seems to be better than the unimodal condition for each question in SSQ questionnaire. To conclude with the Outcome measures of all test procedures, the subjects with bimodal stimulation perform significantly better than Unimodal stimulation condition. Binaural hearing improves better speech perception in noise with the help of squelch effect, better localization skills with the help of ITD and ILD cues, ease of listening through binaural summation. Bimodal stimulation provides the above mentioned binaural advantages to the hearing-impaired population. This bimodal stimulation is also helpful in restricting the auditory deprivation in the non-implanted side of the individual with bilateral Severe to Profound hearing loss, which in turn will give good prognosis if the CI is done on the other ear later

Keywords: *MCL, SNR, ITD, ILD, CI*

1. INTRODUCTION

Hearing or Auditory perception is the ability to perceive and sense the sound. It is the sense that allows us to distinguish sounds with our ears. The partial or total inability to hear sounds is known as Hearing loss or Hearing impairment. In children, hearing loss may affect the ability to learn spoken language and it may affect the child's Receptive and Expressive language skills; whereas in Adults, hearing loss may affect their social life and other work-related activities; thereby affecting their Quality of life. There are various types of hearing loss solutions available at present which includes Hearing aids (HA), Cochlear Implants (CI) and Auditory Brainstem Implants (ABI). CI stimulates the inner ear with electrical signals and sends those signals to the auditory nerve. The electrodes will stimulate the cochlear nerve, which in turn sends impulses to the brain where they are interpreted as sound. There are certain processing strategies that are being implemented nowadays to make the sound seem more natural. Hearing Aids are the amplifying device that amplifies sounds to a person who has partially impairment in hearing. The primary benefit of HA over a CI is the low frequency gain, low- frequencies are being coded at the apex of the cochlea, CI limits the insertion depth of the electrode array thereby limiting the access to lower frequencies below 250Hz.Thus the Low frequency information of the signal is provided with a hearing aid. Therefore these devices can be fitted binaurally to achieve certain benefits. Binaural fitting would help in achieving benefits of binaural hearing. Binaural Hearing is known as the perception of sound stimulation in two ears, where inputs from each ear travel up to the auditory cortex via two pathways. One is the Ipsilateral Pathway and the other is the Contralateral Pathway. These two inputs are compared and processed at various nuclei in the auditory pathway before reaching the Cortex. Binaural hearing allows the listener to make use of variety of auditory cues such as Interaural level and time differences that result in specific benefits. Binaural hearing gives significant benefits compared with monaural hearing with the help of these auditory cues. Bimodal Stimulation is where one ear is fitted with CI and the other ear is fitted with HA. Binaural benefits can be achieved with Bimodal Stimulation for subjects with bilateral hearing difficulties. Many Studies reveal that subjects with Unimodal Stimulation tend to have poor speech intelligibility, localization difficulties, musical perception difficulties and also deficits in speech perception at noisy environment as well as in reverberated rooms as low frequency cues may be missed out by CI device (Fu, Shannon, & Wang, 1998; Stickney, Zeng, Litovsky & Assmann, 2004).Binaural perception as well as Bimodal Stimulation includes two phenomena which serves as the basis; which includes, Complementary Integration, Redundant Integration. Complementary Integration is where the Brain combines High Frequency from CI and Low Frequency from HA; Redundant Integration is which that encodes similar speech information at brain from both ears. There are primarily three effects to Binaural Hearing which includes. The Head shadow effect, Binaural summation effect and, Binaural squelch effect. In day-to-day environment, humans are proficient enough to listen to one's speech in the presence of other conversations and noise. Even though there are multiple sound sources, normal hearing individuals are able to recognize and understand the target speech and are able to ignore the unwanted background noise. This ability of a human to attend to the relevant speech and simultaneously ignore the irrelevant messages or signals in the background is termed as Cocktail Party Effect which has been defined by Colin Cherry in the year 1953. Speech Perception in noise and Localization are the major and difficulties faced by a hearing-impaired individual. Because of these difficulties they experience a communication breakdown in their life. This perceptual ability in presence of other background noise can be improved to some extent with bimodal stimulation. Many studies have been done to evaluate the bimodal benefits and have reported significantly better performances when compared with Unimodal condition alone in case of Speech perception in noise and Localization abilities (Armstrong, Pegg, James& Blamey, 1997; Ching, Incerti & Hill, 2004; Tyler et al., 2002). Studies on Musical perception also reveal satisfactory perception and better performance with Bimodal Stimulation (Arnoldner et al., 2007). Bimodal benefits have been evaluated by various authors since 1997. Adult's preferences to use bimodal stimulation predominantly lies on the 'naturalness' of music, 'quality' of speech and in 'clarity' of one's own voice. In case of children, parents have preferred bimodal stimulation over Unimodal stimulation based on the child's improved social functioning abilities, ease of communication and enhanced confidence level of the child when using bimodal devices. Both children and adults commented on increased directional hearing, sense of security and of sounds perceiving in the middle of the head rather than on one side (Armstrong et al., 1997; Blamey, Armstrong & James, 1997; Ching et al, 2004; Tyler et al., 2002; Syms&Wickesberg2003).

1.1. The need for the Study

Subjects with Unimodal stimulation tend to face certain difficulties in Musical and Speech Perception even with advanced Coding Strategies and these difficulties are being reduced with the use of Bimodal Stimulation. Whereas Bimodal Stimulation have not been widely recommended for the past few decades and this has been into focus as of now. In addition, there were many studies which support bimodal stimulation over bilateral stimulation in Localization as well as in Musical and Speech perception; but none has profiled the outcome measures with Bimodal Stimulation under various circumstances. With these considerations, the current study focuses on Profiling Outcomes of Speech perception in noise, Pitch pattern test and the range of hearing disabilities across several domains using The Speech, Spatial and Qualities of Hearing Scale in children with Bimodal Hearing.

1.2. Aim

Profile the Bimodal benefits in clients with Cochlear Implants.

1.3 Objectives

i) To measure Speech perception in Noise (SPIN)
ii) To measure Pitch Pattern differentiation ability(PPT)
iii) To measure the range of hearing disabilities across several domains using The Speech, Spatial and Qualities of Hearing Scale (SSQ)

2. METHODOLOGY

The current study investigated the outcome of the bimodal hearing in terms of speech perception in noise, pitch pattern differentiation ability and also the range of hearing disabilities across several domains using The Speech, Spatial and Qualities of Hearing Scale (SSQ).

2.1. Subjects

A total of 15 Subjects with bimodal hearing with age range of 6 - 20 years have participated in the study.

2.2. Inclusion Criteria

- Bimodal hearing with a minimum one-year hearing experience
- Complete insertion of electrodes with no malfunctioning of electrodes
- All subjects with patent inner ear and auditory nerve.

Exclusion Criteria

- Bilateral CI
- Anomalous Cochlea
- Partial insertion / malfunctioning electrodes
- Associated abnormalities

2.3. Test Environment

Speech Perception test, Loudness Scaling and Pitch Pattern test were carried out in a free field sound-treated room with permissible noise limits according to ANSI (1983). The administration of SSQ was carried out in a one-to-one setting.

2.4. Test Equipment

The stimulus for Speech Perception in Noise and Loudness Scaling was delivered through 'Piano Inventis' Audiometer, the stimulus for Pitch Pattern Test was delivered using 'Piano Inventis' Audiometer compatible with Windows 8 Laptop.

2.5. Stimuli

2.5.1. The Loudness Scaling

Loudness Scaling was obtained using speech stimulus.

2.5.2. Speech Perception in Noise

A phonetically balanced word list of the subject's native language was taken and was randomly presented in order to avoid the word order effect and familiarity. The target word lists consist of 25 phonetically balanced words.

2.5.3. Pitch Pattern Test

Prototypic frequency pattern is composed of three 150 ms tones (10 ms Rise – fall time) and 200 ms inter-tone intervals. The tones in each frequency pattern are combinations of two sinusoids, 880 Hz, and 1122 Hz, which are designated as low frequency (L) and a high frequency (H) respectively. Thus six possible combinations of the three-tone sequence were used (LLH, LHL, LHH, HLH, HLL, and HHL). The tones were generated digitally and shaped with a cosine- squared function. The CD consists of 60 frequency patterns (six patterns that are with ten randomizations) that have approximately six secs of inter-pattern intervals.

2.5.4. The Speech, Spatial and Qualities of Hearing Scale (SSQ)

The SSQ questionnaire is designed to measure a range of hearing disabilities across several domains (Gatehouse & Noble, 2004). Particular attention is given to hearing speech in a variety of competing contexts and to the directional distance and movement components of spatial hearing. The speech domain consists of 14 questions, the spatial domain consists of 17 questions and the qualities domain consists of 19 questions.

2.6. Procedure

The primarily objective evaluation was done by measuring Impedance Field Telemetry (IFT) for all the subjects, which gives us a clear picture about the integrity of the electrodes contacts as well as the status of the electrodes. HA was also been checked for proper functioning priory.

All the subjects were made to sit individually in an acoustically sound treated audiometric room and the same set up was carried out throughout the test procedure. The informal listening check was done with ling sounds (/a/, /i/, /u/, /m/, /s/, /ʃ/) and with 5 random questions from a distance of 5 feet under three conditions like HA alone, CI alone and Bimodal Hearing.

Aided responses were obtained for frequencies ranging from 250Hz to 8 KHz under three conditions (i.e.) Unimodal Condition – HA alone with optimized hearing aid gain, CI alone with their stabilized MAP and Bimodal Condition.

2. Loudness scaling.

Loudness scaling was attempted initially to obtain the most comfortable level for Pitch Pattern Test by presenting speech stimuli at 0^{o} azimuth at various levels; the subjects were instructed to rate their minimum audible level and the intolerable level as one and seven respectively. The most comfortable level was instructed to be rated somewhere in between one to seven. The loudness level at which the subjects have rated four is taken at the presentation level.

2.6.1. Speech Perception in Noise.

Speech perception in noise was obtained by presenting 25 phonetically balanced PB words in the presence of noise at 0º azimuth with a variable signal to noise ratio from +15db SNR under three conditions, with Hearing aid alone, Cochlear Implant alone and Bimodal Hearing. The subjects were instructed to listen to the speech stimuli presented and to repeat it immediately after the clinician's production and their responses were scored in percentage. If the words were not correctly repeated then the noise level was varied in 2dB steps until 50% correct responses were obtained. The Signal to Noise ratio required to obtain 50% correct responses was noted.

2.6.2. Pitch Pattern Test

60 frequency patterns (6 patterns with10 randomization) that have approximately 6 sec inter pattern intervals were used. 6 trials were given initially for familiarization which is then followed by 30 test trials. The stimulus was delivered at 0º azimuth for all three conditions at the most comfortable level obtained by loudness scaling procedure. The subjects were asked to describe the pitch perceived by drawing a short line for a low pitch and a long line for high pitch. Those sheets were evaluated based on the standardized key sheet. The test procedure was carried out in three conditions HA alone, CI alone and Bimodal hearing

2.6.3. The Speech, Spatial and Qualities of Hearing Scale (SSQ)

The SSQ questionnaire was administered in one to one setting and the subjects were asked to rate all the questions which have been classified under three domains on a 0 to 9 point rating scale under three conditions; HA alone, CI alone and Bimodal Hearing.

3. RESULTS AND DISCUSSION

The aim of the present study is to profile the Outcome of subjects with Bimodal hearing in terms of speech perception in noise, pitch pattern sequencing ability and also the range of hearing disabilities across several domains using the Speech, Spatial and Qualities of Hearing Scale (SSQ). Data were collected from 15 subjects with the age range of 6 – 20 years and was analyzed for statistical significance using Statistical Package of Social Science (SPSS) software version 16.0.

3.1. Aided Responses

Aided responses were obtained for frequencies ranging from 250 Hz to 8 KHz under three conditions.

Table 3.1: The Mean Unaided and Aided Thresholds of the Subjects on the Contralateral Ear to the Implant.

Condition	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Mean Unaided Thresholds	80.33	86	91.66	91	96.33	100
Mean Aided Thresholds	49.33	54.33	58.66	61	60.66	63.66

Note. Hz- Hertz.

The Table 3.1 summarises the mean unaided and aided thresholds in the ear contralateral to the implanted side. The unaided thresholds are in the range of severe to profound degree, whereas the aided thresholds vary between moderate to moderately severe levels. Subject 1 and subject 2 had poor aided thresholds ranging from 70dB to 105dB.

Table 3.2: Mean Aided Thresholds on the Implanted Side.

Condition	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Unaided Thresholds	84	89.33	97	101	105	103
Aided Thresholds	34.33	33	36.66	39	40	38.33

Table 3.2 depicts the mean thresholds before implantation (unaided) and aided thresholds with CI. The aided thresholds with CI are within 33-39dBHL.The mean aided thresholds with the bimodal condition have been depicted in Table 4.3 and it ranges between 28-38dBHL.

Table 3.3: Mean Aided Thresholds on Bimodal Condition

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	6kHz	8kHz
Bimodal Aided Thresholds	29.66	28.33	33.66	36.33	38	37.66	36.66

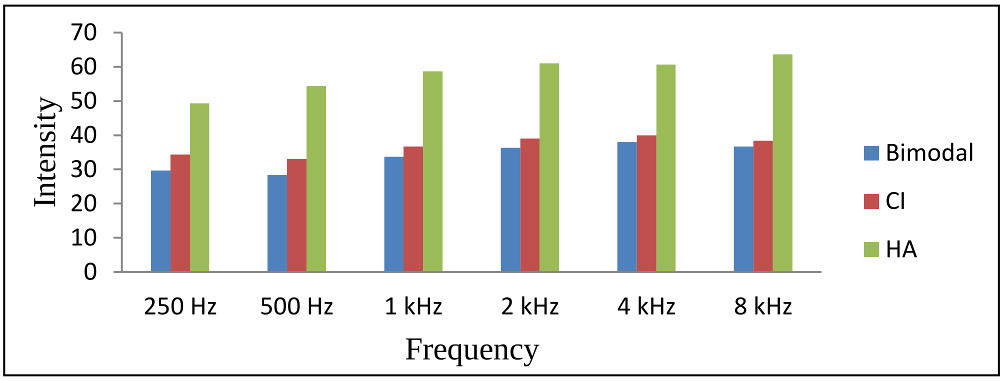

Figure 3.1: Depicts the mean aided thresholds across frequencies obtained with the bimodal condition, CI alone condition and HA alone condition

In summary, the aided thresholds are better for the bimodal condition than the Unimodal condition. From figure 3.1 it is evident that the aided thresholds with CI alone condition are better than the aided thresholds with HA alone condition. The improvement in aided thresholds from HA to CI ranged between 15dB – 25dB, from HA to bimodal ranged between 19dB – 27 dB and improvement from CI to bimodal ranged between 1dB to 5 dB. The improvement in mean aided thresholds in Bimodal condition is in good correlation with the study done by Schoen et al., 2002, where a mean of 4 dB improvement in thresholds, presumably due to binaural redundancy was noted with binaural input.

3.2. Comparison of Speech Perception in Noise scores under three conditions i.e., HA alone, CI alone and Bimodal Hearing

The Signal to noise ratio required to obtain 50% scores for Speech perception in noise was obtained under three conditions using variable SNR procedure. It can be inferred that greater SNR is needed for HA alone condition followed by CI alone and the least SNR was required while the SPIN test was done using bimodal condition for all the subjects indicating that bimodal hearing improves speech perception in noise. The individual scores of SNR 50 are graphically represented in figure 3.2.

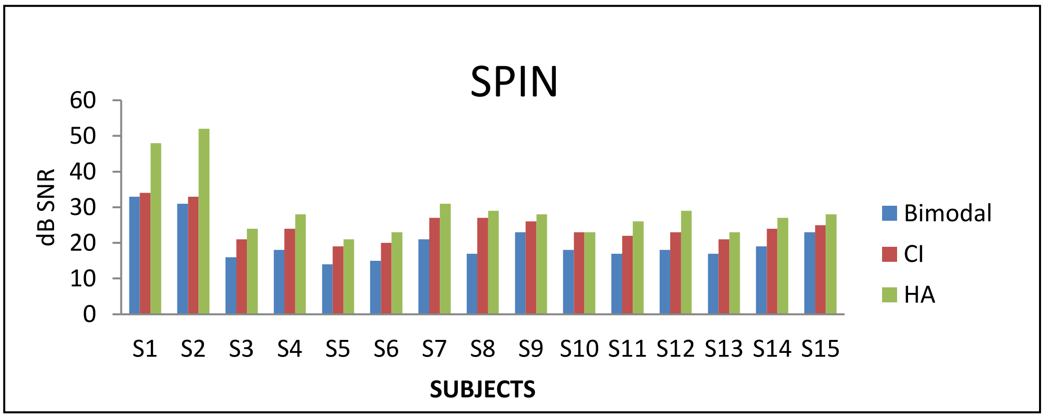

Figure 3.2: The Signal to Noise ratio required to obtain 50 % scores under three conditions for each subject has been depicted

The mean SNR required to obtain 50% scores for Speech Perception in noise are depicted as follows. In case of bimodal condition, an average of +20 dB SNR was required to obtain 50% scores. Subject five required a minimum of +14 dB SNR and Subject one required a maximum of +33 dB SNR to obtain 50% scores for Speech perception in noise test. In case of CI alone condition, mean of +24.6 dB SNR was required to obtain 50% scores. Subject five required a minimum of +19 dB SNR and Subject one required a maximum of +34 dB SNR to obtain 50% scores. In case of HA condition, mean of +29.3 dB SNR was required to obtain 50% scores. Subject five required a minimum of +21 dB SNR and Subject two required a maximum of +52 dB SNR to obtain 50% scores. Subject 1 and 2 uses hearing aids only for about 5 hours per day whereas subjects 7 and 12 uses hearing aids for about 8 hours per day. These four subjects were using CI regularly. All other subjects use the hearing aids throughout the day along with CI on a regular basis. Subjects 1 and 2 required greater SNR of about 14dB and 19dB respectively. Subjects 7 and 12 required SNR of about 4dB and 6dB respectively. The effect of thresholds on the contralateral ear and usage time of HA and its impact on outcome measures can be supported with the evidence from the study done to find out the bimodal benefits, It was noted that on an average better performances in bimodal condition in case of threshold was noted and the usage time of the HA impacted the outcomes of the study (Waltzman et al., 1992). Continuous use of an Implant and a contralateral HA has resulted in a significant advantage in speech perception task overuse of an implant alone for 50 adults with bimodal stimulation (Blamey et al., 1997). Five subjects (subject 6, 9, 11, 13, 15) have greater hearing experience with CI than bimodal. Therefore the difference in SNR50 between CI and HA ranged from 2-4dB, with lesser SNR in CI alone condition. Six subjects (Subject 3, 4, 5, 8, 10 and 14) had greater hearing experience with HA than CI. Subject 10 had 6 years of hearing aid experience before going for bimodal hearing. This particular subject required same amount SNR to score 50% with both CI alone and HA alone. Subjects 3, 4, 5, 8 and 14 had at least one to four years of prior experience with HAs before opting for bimodal hearing. These 5 subjects required 2-4 dB less in SPIN test with CI alone when compared with HA alone.

In summary, the subjects who have a regular bimodal hearing and the subjects who have greater hearing experience with HA than bimodal hearing have 0-4 dB SNR improvement when using CI alone compared with HA alone. Subjects 7 and 12 who have the bimodal hearing of at least 8 hours per day had SNR improvement of about 4-6 dB in CI alone compared to HA alone. Subjects those who rely more on CI (less than 5 hours per day usage of hearing aid for bimodal hearing) had a greater difference in SNR50 between CI alone and HA alone. The effect of binaural redundancy produces a significant improvement in mean SNR scores obtained with bimodal stimulation than with Unimodal stimulation. A mean of +4 dB SNR improvement in signal to noise ratio obtained with bimodal stimulation when compared with CI alone condition is noted to obtain 50% response in speech perception in noise test in the present study. This is in good agreement with the previous studies related to binaural redundancy effect. In normal hearing individuals, binaural redundancy effect produces an improvement of 1-2 dB in signal to noise ratio (Bronkhorst & Plomp, 1998). Mean of 4 dB improvement in SNR, presumably due to binaural redundancy is noted with bimodal input (Schoen et al., 2002).

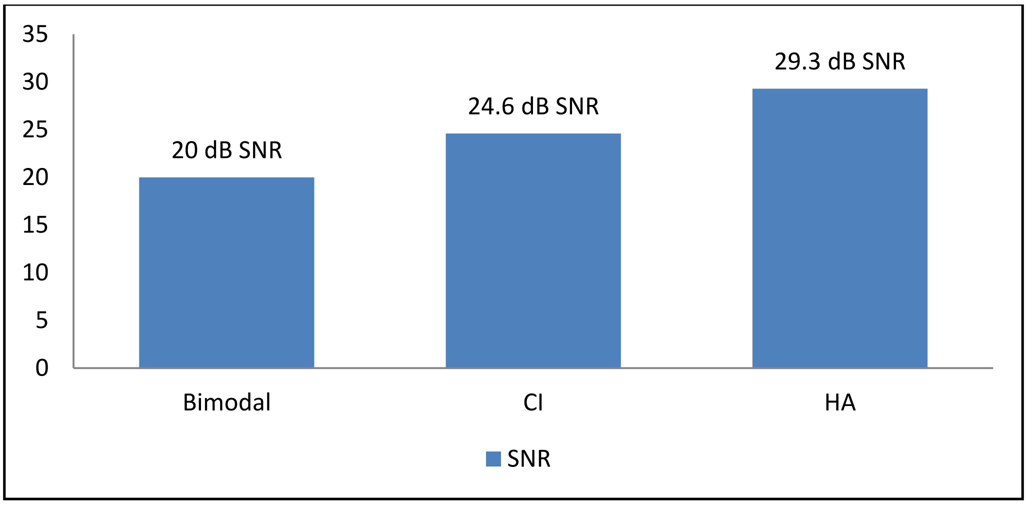

Figure 3.3: The mean SNR value for each condition is depicted in the form of bar diagram.

In case of Unimodal stimulation, subjects perform better with a mean score of 24.6 dB SNR in CI alone condition when compared HA alone condition with a mean of 29.3 dB SNR. The improvement in scores obtained with CI alone condition can be supported with the study done by Shallop et al., 1992, 80% of the subjects scored significantly higher when using CI alone condition when compared to HA alone condition on the Iowa Sentences Without Context Test, and the NU-6 word test scored for phonemes. The CI superiority over HA is due to the thresholds on the ear contralateral to the implant (Severe to Profound hearing loss). In presence of noise more favorable SNR is needed with Unilateral input than with bimodal input to perform the same in quiet (Au et al., 2003). This effect is also being noted in the present study. Subjects with greater implant age, prolonged usage of implant and hearing aids required only a minimum signal to noise ratio to acquire 50% response in speech perception in noise test in all three test conditions, In case of Bimodal condition the mean SNR required to obtain 50% scores in SPIN for Subject 5 with an implant age of 5 years and 8 months is +14 dB SNR , whereas the mean SNR required to obtain 50% scores in SPIN for Subject 1 with an implant age of 2 years and 4 months and also with the history of using implant for only limited duration of time in a day is +33 dB SNR. Similarly in CI alone condition, Subject 5 with an implant age of 5 years and 8 months requires a minimum of +19 dB SNR to obtain 50% scores in SPIN whereas Subject 1 with an implant age of 2 years and 4 months and also with the history of using implant for only limited duration requires a maximum of +34 dB SNR to obtain 50% scores for Speech perception in noise test. In case of HA alone condition, Subject 5 requires a minimum of +21 dB SNR and Subject 2 with the history of using the implant for the only limited duration of time requires a maximum of +52 dB SNR to obtain 50% scores for Speech perception in noise testing.

Kruskal-Wallis H test was done to check if the mean scores for the SPIN test are significantly different between the three listening conditions. The results show that there is a very good statistical significance (p= 0.000) in the mean SPIN scores between the three different conditions. Post Hoc analysis was done to identify between which two listening conditions there was a good level of significance. Mann-Whitney U test reveals that there is very good level of significance between Bimodal condition and HA alone condition (p=0.001), followed by Bimodal and CI alone condition (p = 0.003). The p-value approaches the level of significance between CI alone condition and HA alone condition (p= 0.050). The statistical difference in mean scores of SPIN just attained significance and this could be due to the greater SNR needed in HA alone condition by the subjects 1 and 2 (both uses a hearing aid for less than four hours per day).

3.3. Comparison of Pitch Pattern Test scores under three conditions i.e., HA alone, CI alone and Bimodal Hearing

Pitch pattern sequencing test was done under three conditions at MCL with 30 test items and the scores were obtained in percentage. The mean Pitch pattern scores reveal that higher scores were obtained for Bimodal condition followed by CI alone condition. HA alone condition had the least percentage scores for Pitch Pattern Sequence test. Subject 1, 2 and 3 had same scores for both Bimodal and CI alone condition.

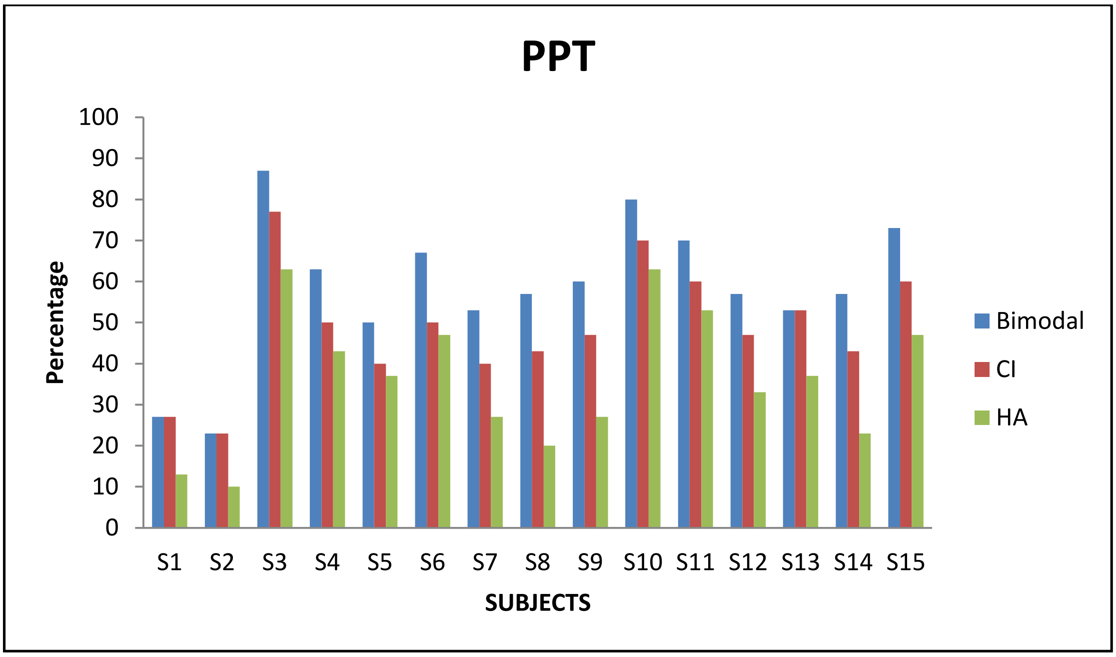

Figure 3.4: Depicts the Pitch Pattern test scores obtained under three conditions for all the subjects.

From the figure 3.4, it can be noted that the bimodal pitch pattern sequencing scores are better than CI alone condition and the least scores were seen for HA alone. Least scores in case of the bimodal condition are noted for the subject S1, S2, and S13. Subjects S1 and S2 use HA only for a limited duration. This trend was not seen in subject 13. In case of bimodal condition, mean of 58.4% scores are obtained. Subject 2 had the poor score of about 23% and subject 3 got the maximum score of about 87%. In case of CI alone condition, mean of 48.6% scores are obtained. Subject 2 had the poor score of about 23% and subject 3 got the maximum score of about 77%. In case of HA alone condition, mean of 36.2% scores are obtained. Subject 2 had the poor score of about 10% and subject 3 got the maximum score of about 63%.

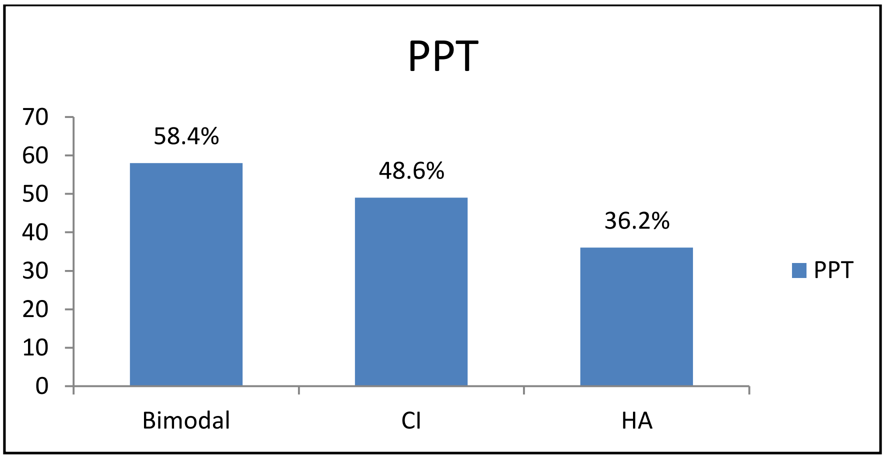

Figure 3.5: The mean pitch pattern scores obtained under three conditions is depicted in the form of a bar diagram.

The result of CI alone condition with a mean of 48.6% in the present study is in good agreement with the study which aims to find out the temporal organization capacity in users of multichannel CI, where the results show that the CI users had good performance in Pitch pattern task with a mean of 48.7% (Campos and Alvarenga., 2008). Kruskal-Wallis H test was done to check if the mean scores for PPT test is significantly different between the three different listening conditions and the results shows that there was a statistically significant difference in PPT scores among three different conditions (p=0.003) Post Hoc analysis was done using Mann-Whitney U test to find the level of significance between each of the three listening conditions. The results reveal that there was the very good significant difference in Pitch Pattern test scores between Bimodal and HA alone condition (p=0.002). The performance between Bimodal and CI alone condition as well as CI alone and HA alone condition is significant with p values (p = 0.046) and (p=0.048) respectively. The low-frequency pitch related cues are better perceived in the ear with HA and the high-frequency information from the ear with CI and these are integrated at the level of the central auditory nervous system thereby enhancing the overall music perception compared to only CI condition. The difficulty with musical perception and identifying tone of voice may be due to the pitch coding in CI processing. The alternative way to improve electrical pitch perception is to use the residual acoustic hearing with an HA on the contralateral ear. This has been tested using four pitch-related tasks like HINT, Montreal Battery of evaluation of amusia, Aprosodia battery, talker identification using vowels was used. In these entire four tasks, the bimodal group did perform better than the bilateral group on almost all tests. (Cullington and Zeng, 2011).

3.4. Comparison of Subjective perceptual rating The Speech, Spatial and Qualities of hearing scale under three conditions i.e., HA alone, CI alone and Bimodal Hearing

The SSQ questionnaire was designed to measure a range of hearing disabilities across three domains. Where particular attention is given to hearing speech, spatial and quality in a variety of competing for context. The subjects have been instructed to rate the questionnaire on a 10-point rating scale where the subjects have to rate between 0-9 where 0 indicates “Not at all” and 9 indicates “perfectly” across three conditions. Each of the three domains was analyzed separately.

3.4.1. Speech domain.

The speech domain consists of totally 14 questions. By comparing the mean scores and standard deviation obtained for each question the speech perceptual rating of bimodal condition seems to be better than cochlear implant alone condition which is better than hearing aid alone condition. Statistical analysis of perceptual rating of speech domain across three conditions was done. Kruskal-Wallis H test showed that there was a statistically significant difference in perception of speech among three different conditions, p=0.000. Post Hoc analysis was done by using Mann – Whitney U test to identify between which two listening conditions there is good significance difference. The results indicated that the Speech perceptual rating scores were highly significant for Bimodal and HA alone condition, p=0.000 and also for CI alone and HA alone condition, p=0.000, Bimodal condition and CI alone condition has a good level of significance p=0.003.

3.4.2 Spatial domain.

The SSQ questionnaire was also designed to measure a range of hearing disabilities with respect to the spatial orientation of objects and localization ability in a different context. By comparing the mean scores and standard deviation obtained for each question the perceptual rating of bimodal condition seems to be better than CI alone condition which is better than HA alone condition. Spatial location of soft sounds like locating lawnmower, door slam in an unknown place, sounds that come from above or below, Voice or footsteps from distance, Lateral movement and direction of voice or footsteps seems to be difficult and has a minimal rating in all three conditions. Kruskal-Wallis H test was done and it showed that there was a statistically significant difference in perception of spatial among three different conditions, p=0.000. Post Hoc analysis was done to identify between which two listening conditions there is good significance difference, using Mann-Whitney U test which indicated that the Spatial perceptual rating scores were highly significant for Bimodal and HA alone condition, p=0.000, for CI alone and HA alone condition, p=0.000 and also as well for Bimodal condition and CI alone condition p=0.000.

3.4.2. Quality domain.

The quality domain consists of 19 questions based on the subjective perception of sounds, music, and its naturalness. By comparing the mean scores and standard deviation obtained for each question the perceptual rating of bimodal condition seems to be better than cochlear implant alone condition which is better than hearing aid alone condition. Certain conditions like separating one sound from another, distinguishing and identifying musical instruments, the perception of one’s own voice, the perception of sounds with either implant/aid when off seems to be difficult. Statistical analysis of perceptual rating of a quality domain across three conditions was done. Kruskal-Wallis H test showed that there was a statistically significant difference in perception of quality among three different conditions, p=0.000. Post Hoc analysis was done to identify between which two listening conditions there is good significance difference, using Mann-Whitney U test which indicated that the Quality perceptual rating scores were highly significant for Bimodal and HA alone condition, p=0.000, for CI alone and HA alone condition, p=0.000 and also as well for Bimodal condition and CI alone condition p=0.000

The overall mean and standard deviation for the speech, spatial and quality domain was also analyzed separately in order to find out the domain effects in all three conditions. It can be inferred that the mean scores of Bimodal conditions across the speech, spatial and quality domain obtained in the present study is in good correlation with the study done by Christal in the year 2012 where the subjects have got a lowest mean rating score of 4 (SD: 2) in spatial domain and a mean rating score of 5 (SD: 1) in speech domain and has the highest rating, with a mean rating score of 6 (SD: 2) in quality domain. The subjects in the present study have also reported about usage time of hearing aid on the contralateral ear. Subject 1 and Subject 2 uses HA only for a limited duration of time in a day. This subjective preference on bimodal stimulation is also noted in many studies which aim to evaluate the bimodal benefits. 80% of users with bimodal hearing for more than 8 hours per day on average have rated the bimodal condition superior to CI alone (Cowan, Chin-Lenn ,2004)and about 60% of bimodal users’ report using hearing aid for more than 50% of time and does not wants to take off it (Fitzpatrick et al., 2010).

4. SUMMARY AND CONCLUSION

Subjects with Unimodal stimulation tend to face certain difficulties in Musical and Speech Perception even with advanced Coding Strategies and these difficulties can be reduced with the help of Bimodal Stimulation. The current study aims to investigate and profile the Outcome of Bimodal hearing in terms of speech perception in noise, pitch pattern differentiation ability and also the range of hearing disabilities across several domains using The Speech, Spatial and Qualities of Hearing Scale (SSQ) in 15 subjects with bimodal hearing of age ranging between 6- 20 yrs. The findings of the present study can be summarized as bimodal hearing is always better than unimodal hearing. The results of the speech perception in noise test reveal that subjects with bimodal stimulation have shown a mean of +4 dB SNR improvement in signal to noise ratio when compared with CI alone condition to obtain 50% response in the present study. This proves the effect of binaural redundancy which produces a significant improvement in mean SNR scores obtained with bimodal stimulation than with Unimodal stimulation. The temporal organization capacity of subjects with bimodal stimulation is tested with Pitch pattern test. From the results of the test, it can be concluded that the subjects with Bimodal stimulation have shown good performance with a mean percentage of 58.4% than unimodal conditions (CI alone and HA alone). Subjective perception of Speech, Spatial and Quality rating was rated across all three conditions i.e., Bimodal condition, CI alone condition and HA alone condition. The results of SSQ was analysed which reveals that question wise the mean rank observed in all three domains were not similar, which in turn indicates that the scores obtained in all three conditions were significantly different ($p<0.05$). Also by comparing the mean scores and standard deviation obtained for each question in all three domains the perceptual rating of bimodal condition seems to be better than the unimodal condition. It can also be noted from the mean ranks of each question across a different condition in Speech, Spatial and Quality domain that each question has a significant contribution with respect to perception across conditions thereby highlighting the validity and effectiveness of the questions included in the questionnaire. The Present study profiled the benefits of Bimodal hearing over Unimodal hearing using the scores obtained from Speech Perception in Noise, Pitch Pattern sequence test and Subjective perceptual rating of the speech, spatial and qualities hearing scale (SSQ). To conclude with the Outcome measures of all test procedures, the subjects with bimodal stimulation perform significantly better than Unimodal stimulation condition. Binaural hearing improves better speech perception in noise with the help of squelch effect, better localization skills with the help of ITD and ILD cues, ease of listening through binaural summation. Bilateral CI provides all the above mentioned binaural advantages to improve the overall quality of hearing in subjects with Bilateral Severe to Profound hearing loss. In certain cases where Bilateral CI is not possible due to various reasons, in that case, bimodal stimulation can be recommended. Bimodal stimulation also provides the above mentioned binaural advantages to the hearing-impaired population. This bimodal stimulation is also helpful in restricting the auditory deprivation in the non-implanted side of the individual with bilateral Severe to Profound hearing loss, which in turn will give good prognosis if the CI is done on the other ear later. Therefore, the subjects who cannot undergo bilateral implant due to various reasons can be benefitted with Bimodal stimulation and can avoid auditory deprivation in the non-implanted ear.

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