CHANGES IN HEARING AID BENEFIT OVER TIME

Register No. M9814

An Independent Project Submitted as part fulfillment
for the first year M.Sc. (Speech & Hearing) to University of Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING. MYSORE-570006
MAY-1999

Certificate

This is to certify that the independant project entitled "Changes in Hearing Aid Benefit Over 'Time" is a bonafide work done in part fulfillment for the degree of Master of Science ((Speech and Hearing) of the student with Register No. M9814.

Mysore

May 1999

Director

AllIndiaInstituteof

Speech & Hearing,

Mysore - 570006

Certificate

This is to certify thai the independant project entitled "Changes in Hearing Aid Benefit Over Time" has been prepared under my supervision and guidance.

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May 1999

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Declaration

I *hereby declare that this independent project entitled'" Changes in Hearing Aid Benefit Over Time" is the result of my own study under the guidance of Mrs. Manjula P.Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing Mysore, and has not been submitted earlier at any other University for any other Diploma or Degree.*

Mysore *RegisterNo.M9814*
May 1999

To

The Lord Venkateshwara

&

My Family

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INTRODUCTION

The provision of amplification via a hearing aid is an almost universal component of rehabilitation regimes for individuals with hearing disability. What happens when people who have lived with untreated hearing loss get their first hearing aid? With provision of a hearing aid speech cues that may have been inaudible become amplified and available to the listeners. Can these listeners immediately make the most efficient use of the newly processed speech information that the hearing aid provides? Is there some period of time after the hearing aid fitting during which people learn or relearn to use additional speech information?

Gatehouse (1989) has presented a hypothesis of perceptual acclimatization to explain the premise that in long-term users of a monaural hearing aid, the ear that is normally aided performs better than the normally unaided ear at high presentation levels, whereas at lower intensity levels the converse is true. This intensity dependence is put forward as evidence that an ear, which is accustomed to receiving a high level of stimulation, will 'acclimatize' to the pattern of speech cues present and be most efficient in analyzing at high presentation levels. At lower presentation levels the normally unaided ear receives its accustomed pattern of cues and so performs better than the normally aided ear.

This acclimatization hypothesis was presented as an alternative to auditory deprivation of late onset, where subjects using monaural amplification exhibit a relative decrement in speech identification scores from the normally unaided ear relative to the normally aided ear , while in contrast, individuals using no amplification or binaural amplification show no such interaural discrepancies. These findings have been interpreted as a reflection of decrease in analyzer capacity in ear, which suffers a deprivation of auditory stimulation relative to the contralateral ear. Gatehouse (1989) argued that it was more parsimonious to explain both his data and previous reports interms of acclimatization effect rather than a deprivation effect.

Several recent investigations of this time course of hearing aid benefit were prompted by the considerable interest of both clinicians and researchers. Yet, results from those studies have been equivocal. Some have found significant increases in hearing aid benefit after the provision of new hearing aids, others have shown no significant changes and some others have shown significant increases only for a limited set of listening conditions.

Gatehouse (1992) used the term "perceptual acclimatization", where as Cox and Alexander (1992) described the effect as "maturation". Both these terms refer to "an improvement in speech recognition overtime as a person learns to use newly available speech cues made audible by the hearing aid amplification". Arlinger etal.,(1996) converged to use the term "auditory acclimatization" to this effect and defined it as "a systematic change in auditory performance with time, linked to a change in the acoustic information available to the listener. It involves an improvement in performance that cannot be attributed purely to task, procedural or training effects".

Robinson and Sumnerfield (1996) defined stimulus learning of specific features of the stimulus set, and said that acclimatization is a good example for stimulus learning, which is specific to the ear of aiding as well as to the frequencies and levels normally provided by the hearing aid. They have also theorized that the stimulus learning has inter individual variations because of the modulators of learning such as duration of hearing loss, type of hearing loss, etc.

Willott (1996) attributed the auditory plasticity as the mechanism responsible for the phenomenon of acclimatization. He described three types of auditory plasticity that determine the amount of acclimatization. He said that the plasticity could have either positive or negative effects in hearing impaired person prior to the use of a hearing aid. If it has positive effects then the hearing is counter indicated when these effects are irreversible. Conversely, if the positive effects are reversible, acclimatization progresses.

Turner, etal., (1996) defined hearing aid benefit as the improvement in hearing ability due to the hearing aid. Hearing ability can further be subdivided into objective and subjective measures. With objective measures including tests of speech recognition yielding numerical scores of "percent correct" or something similar and subjective measures including questionnaire or interview responses.

Although the researchers of acclimatization stick on to a similar definition, the results vary from study to study. They indicate a mean improvement in benefit over time in the range of 0 to 10 % across a wide range of speech materials and presentation conditions. The time course of acclimatization does not appear to be complete until after at least a number of months. Most of the studies done, make use of speech identification scores as an indicator of acclimatization. It is also suggested that the use of non-speech auditory skill tests, imaging techniques may enhance the available knowledge over acctimatization Studies are also done over the cochlear implant user to demonstrate the effect of acclimatization, where the phenomenon has an entirely different nature.

Hearing aids may also have deleterious effects upon hearing by affecting central and /or peripheral auditory systems. A hearing aid re-introduces sounds which were not heard by a hearing impaired individual. If the brain does not alter its positive effects of changing the frequency and intensity representations, a distortion of the relationship between acoustic stimuli and auditory representation results, which affects speech perception. A hearing aid may damage intact hair cells by delivering over-amplified sounds. It may also damage intact outer hair cells in conditions such as neuropathy. This leads to further deterioration of speech perception.

The aim of the present study is to examine the existence of the auditory acclimatization effect and also to check whether DLI can be used to demonstrate the acclimatization effect.

REVIEW

Does benefit from a hearing aid change over time? The answers to this question lie at the heart of many studies and are critically linked to the definition of hearing aid benefit, as well as to the identification and control of many external factors that can influence hearing aid benefit. The simplest definition of hearing aid benefit is the improvement in hearing ability due to the hearing aid use. Hearing ability can be further divided into subjective and objective measures (Turner et.al,1996), with objective measures including tests of speech recognition yielding numerical scores of "percent correct" or something similar , and subjective measures including questionnaire or interview responses. There is no consensus as to which measure provides a definitive picture of hearing ability or hearing aid benefit.

Although most of the studies are done on sensori-neural hearing impaired, auditory acclimatization can also be seen patients who have suffered from a long term conductive hearing loss. With proper amplification, these subjects too showed auditory acclimatization. Some studies have also focused on the long term changes in the performance of cochlear implant users, both children and adults.

Thus, auditory acclimatization has evidences from different types of rehabilitation groups. Based on the type of rehabilitative device used by the individuals and the purpose of the study, the evidences for acclimatization are drawn from three categories,

I. Accli matization studies on hearing aid users.

II. Acclimatization studies on cochlear implant users and

III. Auditory Deprivation studies.

I. ACCLIMATIZATION STUDIES ON HEARING AID USERS :

These studies were conducted on hearing aid users either in free field or in pressure field conditions with an aim to find out, whether the hearing aid benefit changes over time. They have employed subjective and/ or objective measures. Yet, results from these studies have been equivocal. Some have found significant increases in hearing aid benefit after the provision of new hearing aids and others showed no significant changes. Thus, these studies can be further categorized into:

A. Studies supporting, and

B. Studies refuting,

the existence of auditory acclimatization effect.

LA. STUDIES SUPPORTING THE EXISTENCE OF AUDITORY ACCLIMATIZATION EFFECT.

More than fifty years ago, Watson and Knudson (1940)[as cited in Turner et. al, (1996)] presented data relevant to the time course of hearing aid benefit. The main purpose of their study was to compare patient's word recognition scores under conditions of "selective" versus "uniform" amplification provided via laboratory equipment, and headphones. Results as a function of time are provided, only for one subject eventhough 17 subjects were included in the study. The authors state "some observers, particularly those with a large perceptive loss, do not hear well with uniform amplification, when it is first tried , because they have never heard some of the speech sounds before or have not heard them for a long time". The results were presented for the subject No. 12, who had severe perceptive hearing loss (sensori-neural) at all frequencies. The authors claim that he was acquainted with the word lists before any testing. They observed an increase in speech recognition scores up to over 50% over the course of ten to twelve weeks. However they had not obtained unaided speech recognition scores. Though it is surely a large change in speech recognition scores, the ten to twelve weeks acclimatization period is misleading, in that their subjects did not wear these amplification devices on daily basis, but wore them only during the actual test sessions. Therefore, the acclimatization shown by this subject may actually represent only the most initial portion of the learning curve, perhaps comparable only to what a typical patient seen in a clinic today may experience with his or her new hearing aid within first few hours (learning curve is the graph between performance and time). However, this selected case study is perhaps only interesting from a historical and anectodal perspective, in as much as the results of the other subjects are not presented.

Gatehouse (1989) offered an alternative interpretation of the deprivation effect of the late onset in terms of "perceptual acclimatization ". According to his hypothesis, in monaural hearing aid amplification, the intensity dependence suggested that an ear which is used to receiving a high level stimulation will adapt to the pattern of cues presented and be most efficient at analyzing at high presentation levels. He said that such intensity dependent effects might have gone un-noticed previously because particularly stressing the conditions of perceptual adaptation experiments, or the limited dynamic range and / or loss of neural redundancy via sensory hearing loss, are required to demonstrate them. A test of intensity dependence hypothesis against the deprivation hypothesis involves lower stimulation levels. He tested this hypothesis in a group of hearing impaired individuals with symmetric sensory neural hearing loss who have been the regular users of monaural amplification. They were tested with Four Alternative Auditory Feature (FAAF) test in the presence of noise at fixed presentation levels, presented through headphones to both the ears one after another. The results showed an improvement in performance from 65 to 90 dB SPL , for both the aided and unaided ears. But the improvement is more for the normally aided ear than that of the normally unaided ear with increase in the presentation levels. At 50 dB SPL , the unaided ear performed better than that of the normally aided ear. He said that if the acclimatization effect to the level of presentation of speech holds up across differences in subjects , speech materials, and degree of amplification used, it would be worth applying it to broad frequency regions as well as for speech spectrum as a whole. A valid choice of the best frequency response from the point of view of long term discrimination might only be made after an appropriate period of acclimatization.

Gatehouse (1992) conducted a study to chart the speech identification abilities of individuals with bilateral symmetric sensory neural hearing loss following the provision of a single hearing aid, to provide the evidence on the existence, magnitude and timecourse of any perceptual learning effects. He had measured:

- Puretone thresholds,
- Word recognition scores in quiet,
- Frequency resolution vising psychoacoustic tuningcurves,
- Temporal resolution by minimal detectable duration of a silent interval in a one second, burst of bandpass noise, and
- Speech in noise test with an adaptive FAAF procedure as well as for a fixed S/N ratio, to rule out any asymmetry.

Over twelve weeks from the time of fitting a hearing aid, four subjects using postauricular hearing aid participated in the study. At each visit they were tested for hearing aid insertion gain and speech identification ability in noise with and without a hearing aid in a variety of fifteen conditions. They defined hearing aid benefit as the difference between the aided and unaided speech identification scores. The benefit was measured under headphones as well as in free field conditions. They found a significant change in the benefit after three to four weeks in free-field and pressure field conditions. These more detailed investigations provide more specific evidence for perceptual acclimatization; not only did performance in the head phone equivalent of the aided condition increase, but performance of the headphone equivalent of the unaided condition decreased. The results confirm the presence of substantial perceptual acclimatization effects, which develop over six to twelve weeks after fitting the hearing aid.

Cox and Alexander (1992) reported both objective, ie. 150-item connected speech test (CST) and subjective, ie. Profile of Hearing Aid Benefit (PHAB) data for ten subjects obtained, shortly after the subject received a new hearing aid, and then again ten weeks later. A significant increase in benefit was reported for one (low noise and reverberation with full visual cues) of the four listening environments of CST. The group improvement was approximately 6 r a u (roughly equivalent to 6 % correct .r a u :- rationalized arcsine units). Of the other three environments, two showed non-significant decreases and the third showed a marginally significant increase in benefit. For the PHAB, a significant increase in benefit was reported for all five speech communication sub scales. No control group was included, so the potential effects of subject biases on the PHAB cannot be discounted. Subjects were allowed to adjust the volume controls of their hearing aids at each session, and minor fitting modifications were performed on some hearing aids during the study. The hearing aid again was monitored, however, no significant changes over time were observed. In addition, raw aided and unaided scores are not reported. So it is unknown if any changes in benefit were due to decrease in unaided scores. Nonetheless, their study presented modern evidence for acclimatization and served to heighten the interest in this topic.

Horwitz (1995)[as cited in Turner et. al, (1996)] followed thirteen listeners with newly-fitted hearing aids and also a control group of thirteen longstanding hearing aid users. Both objective ie, 192 item NST and subjective ie, PHAB scores were obtained over an eighteen week period. For the NST testing, two volume control conditons were used: the first with volume controls fixed in the same position as the initials test session; the second allowing the subjects to adjust the volume controls themselves for each session. Group mean NST scores significantly increased for the new hearing aid users in both the fixed and adjusted volume control settings. In contrast, the NST scores for the long standing user group increased only for the adjusted volume control condition. Unaided scores remained stable for both groups. The increase in objectively measured benefit observed in the new-user group was approximately 6%. The subjective measures of benefit did not show a significant improvement in benefit for the users. These results suggested that the acclimatization observed for the objective measure was not dependent on increasing the volume-control settings. Nor was the increase due to procedural learning effects, in as much as a corresponding increase in word recognition was not observed in the fixed volume, longstanding control group. It also suggested that significant increases in objective benefit may not necessarily be accompanied by a corresponding significant subjective improvement.

Cox et.al, (1995)[as cited in Turner et.al, (1996)] measured speech recognition on a 300-item CST and a twenty four item Speech Pattren Contrast (SPAC) test in twenty two elderly first time hearing aid users. The SPAC test is specifically designed to score performance in terms of speech features. Presentation levels of the speech and a background of multitalker babble were held constant in the subject's ear canal over the testing period. In addition a small control group of experienced hearing aid users participated in the - experiment. Over a period of twelve weeks a 4% improvement in speech recognition on the CST was noted in the group data; this difference was statistically significant. No such increase was observed in the control group or in the unaided scores for the test ear. They hypothesised that acclimatization effects would be related to the amount of high frequency gain newly provided to the subjects. This was not supported by the data; however the difference audibility across subjects was relatively small. These authors also hypothesised that acclimatization effects would be exhibited mainly in the high frequency speech sounds in the SPAC. Again the data did not support this hypothesis.

Horwitz and Turner (1997) conducted a study on thirteen new hearing aid users (say group A) and a control group consisting of thirteen longstanding experienced hearing aid users (say group B) were also included. A 192-items NST and a subjective Profile of Hearing Aid Benefit (PHAB) were administered over eighteen weeks, starting on the day of the hearing aid fitting for group A and starting on an arbitrary day at least one year after hearing aid fitting for the group B. At the beginning of each test session subjects adjusted their hearing aid gain while listening to the back ground noise plus fortyeight NST syllables presented in a random order. The subjects were asked to bracket their choosen listening level by first setting the gain too low and then too high before leaving the gain control at the desired position. This bracketing selection was performed three times with the gain control position noted by the examiner each time. The average of three gains was compared as a function of time. The raw percent correct scores were transformed to rationalised arcsine units (r a u). The NST results showed a group average benefit increased by 7 r a u for the new hearing aid users, that is statistically significant. For the control group there was no significant change in benefit. For the group A the adjusted hearing aid gain decreased by an average of 2dB over the eighteen weeks period. However PHAB results showed no significant increase in benefit over time.

Arkis and Burkey (1994) did a retrospective study of patients records and reported, word recognition scores of CNC words for 105 patients; the first measures taken before a hearing aid fitting, the second taken a few months afterward. Seventy of the adults were given monaural hearing aids (mean age = 60.4 years, SD = 12.5), and thirty five were given binaural hearing aids(mean age = 61.5 years, SD = 14.52) A 5 %increase in word recognition was noted for the aided ear. However because all testing was performed at 30 dB SL under headphones. This study did not specifically test the situation for acclimatization occuring under more realistic conditions of listening to newly amplified sound via the patients hearing aid. However the authors found no effect as a function of age and severity of loss upon the amount of benefit change.

Lippy, Burkey and Arkis (1998) conducted a study to examine word recognition scores WRS changes after stapedectomy for far advanced otosclerosis. The WRS changes were examined to determine whether they were consistent with acclimatization or recovery from auditory deprivatism changes that have been seen after the restoration of sound by amplification. In this retrospective study twenty-four patients were selected by including all the cases in which a stapedectomy was performed within the past ten years. One month after surgery the mean WRS had improved by 16.5%. The WRS continued to improve an additional 12%, or more for seventeen of twenty-four patients within two years after their initial postoperative hearing test. The mean WRS improvement within two years of the initial postoperative test was 16.2%. Initial WRS changes were consistent with reports of acclimatization or recovery from auditory deprivation that have been seen after hearing aid use. Finally the authors believe that the overall WRS improvement 32.7% should be taken into account when considering stapedectomy for patients with far advanced otosclerosis.

I.B : STUDIES REFUTING THE EXISTANCE OF AUDITORY ACCLIMATIZATION EFFECT

Taylor (1993) reported hearing aid benefit in fifty eight elderly, new hearing aid users over the course of one year. Both objective (Speech reception thresholds , fifty item NU-6 monosyllables in noise and quiet) and subjective (Hearing Handicap Inventory for the Elderly, HHIE) measures were used. The NU-6 material is concentrated around mid to high frequency speech information. No significant improvements in objective measures for either quiet or noise backgrounds were noted and the HHIE showed changes only for the twelve week measure and this was in the negative direction ie. the benefit reduced. Volume control settings were not fixed in this study and the initial test session did not occur until three weeks after the hearing aid was dispensed. They did not use a control group and no results from unaided conditions are reported.

Bentler et.al (1993 a,b) [as cited in Turner et.al (1996)] published the results from thirty nine new- and twenty six - longstanding hearing aid users over the course of one year. Objective measures included the Speech Perception In Noise (a twenty five item) test and a sixty two item, Nonsense

Syllable Test (NST). The Speech Perception In Noise test is a sentence task , with individual target words being scored. The NST monosyllables emphasize high frequency speech information. Subjective measures included the 'Understanding Speech' subsection of the Hearing Aid. Performance Inventory and a Qualitative judgement test. Significant improvements over time were not noted for most tests, the exception was a subjective measure relating to speech in quiet. Volume controls were set at the initial test session by the investigator. Subsequently, the subject was allowed to set the volume control and some modification of the hearing aid fitting controls were performed throughout the experiment. No unaided control condition was included. Another potentially important factor to be considered is that the new hearing aid users included some patients, who had a trial period experience with hearing aids before the initial test session.

Humes et.al, (1995) [as cited in Turner et.al (1996)] measured speech recognition for 102 item NST syllable lists both in quiet and in noise and the 100 item Hearing In Noise Test over a twenty four weeks period in ten new and ten experienced hearing aid users. All the subjects were fitted with new binaural hearing aids at the beginning of the study. The NST syllables are particularly sensitive to high frequency speech information. The Hearing In Noise Test is a sentence test designed to more closely represent real world communication abilities, and therefore is primarily sensitive to low and mid frequency speech information. In addition, the subjective Hearing Aid Performance Inventory and HHIE scales were also administered. No significant increase over time was noted in any of the measures or groups in the study.

Saunders & Cicnkowski (1997) studied twenty four hearing impaired individuals who wore programmable hearing aids for the first time and a control group of twenty four experienced hearing aid users were also included in the study. Speech reception thresholds in quiet (SRT-Q) were measured with C.I.D W-l spondees and SRT's in noise (SRT - N) were measured with Hearing In Noise Test (HINT) sentences. The HINT material consists of 250 sentences. SRT-N was measured by removing the silences [Subjective SRT-NJ and by preserving the silences | Performance SRT-NJ, The subjects were studied for 90 days. The performance on day 0 was better than any other day. They found an explanation for this result as, the combination of slightly better aided performances coupled with slightly poorer unaided performances on this day. Thus they excluded day -0 and investigation was limited to data obtained on days 30,60,90. There was improvement in performance for the PSRT-N and SSRT-N, although ANOVA showed that these changes were not significant. The changes in SRT-Q were significant between days 30 and 60 but not significant between 30 and 90. Among the configurations of hearing aids used, one with wide band receiver and wide dynamic range compression showed evidence for acclimatization in the SRT-Q and PSRT-N conditions. The authors suggested that this configuration is sensitive to the test materials used, thus there may be and interaction between benefit over time and hearing aid configuration. The authors concluded that if acclimatization does exist, its clinical ramifications are presumably small, because it did not appear on HINT test, even though it has applicability to every day listening conditions.

II. COCHLEAR IMPLANT STUDIES : DEMONSTRATING THE ACCLIMATIZATION EFFECT

In this section, studies demonstrating changes in performance with time by cochlear implant users, have been reviewed. Because implants present an incomplete representation of the speech signal, which often sounds unusual to the patients, we might expect that time would be required for patients to become used to, and to learn to use, these novel signals.

It is possible to fit a hearing aid in less than an hour and administer a test of speech perception to obtain a measure of immediate benefit uncontaminated by effects of learning. However it is not usually possible to obtain data over a short time scale after first activating the speech processor of an implant. Days or weeks may elapse while the electro-auditory sensitivity of the patient is measured and the implant processor is programmed to deliver the most appropriate pattern of electrical stimulation. Only then are formal tests of speech perception administered. As a result, data are generally not available describing the " immediate " speech - recognition performance achieved with an implant. Typically, implant performance has been measured between a week and a month after the speech processor is first activated. It is possible therefore that benefits identified during the first test session already reflect the effects of learning. Despite these limitations , some useful conclusions can be drawn (Tyler and Summer field, 1996).

Dowell et.al, (1986) collected data from forty nucleus multi channel cochlear implant users. They ranged in age from twenty one to seventy one years and the duration of deafness , before implantation ranged from six months to thirty five years and with different etiologies. The patients were evaluated for free field pure tone testing at 500 Hz, 1KHz, 2KHz and 4KHz. The speech testing included the male female voice discrimination test, the four choice spondee test and the C.I.D everyday sentence recognition test. All the subjects were evaluated with the above tests, twelve months post operatively. There were significant improvements in the performance in all the above tests. But the measures are not obtained immediately after the implantation. So, it may not be inferred that the benefit by the cochlear implant has increased over time.

Waltzman et.al, (1986) studied the longterm effects of multichannel cochlear implant (Nucleus - 22) usage on five subjects whose age ranged from twenty two to sixty two years. The duration of deafness before implantation ranged from four to thirty years. The patient's wore their devices ten to sixteen hours per day. The device and the patient's hearing performance was evaluated over an year from the date of implantation. The evaluations included electrical threshold and comfort level measurements for each electrode used, sound field pure tone and speech thresholds, discrimination scores, vowel and consonant recognition tests, the Minimum Auditory capabilities (MAC) tests, and the speech tracking task. Four of the five subjects showed improved consonant and vowel recognition scores whereas the other showed a slight decrease. There was an increase even in the discrimination scores for four of the five subjects. But the amount of current needed for activating each electrode increased.

Spivak & Waltzmann (1990) Conducted a study in order to examine in detail the effects of time and experience on the speech perception abilities of patients using the Nucleus 22 channel cochlear implant. Subjects for their study were fifteen postlingually deafened adults, whose duration of deafness ranged from one year to fifty-seven years. Seven patients were involved in special rehabilitation programs. Speech perception abilities were measured with selected sub tests of the Minimum Auditory Capabilities (MAC) battery. Open set speech recognition was measured with three open set tests : the spondee recognition test, CID sentence test, and the NU-6 monosyllabic word test in recorded voice. The MAC battery was administered to all patients prior to surgery, While wearing a hearing aid. Again at three months after the implantation, and at the end of first , second and third years the testings were repeated in free field condition. Friedman's two way analysis of variance was used to draw if there are any significant difference between the scores over the time. The mean data suggests that improvement in supra segmental scores and segmental score continue at a much slower rate during the period from three months to three years post operatively. There were significant differences in segmental and open-set speech recognition scores over the duration between three months to three years after implantation. Analysis of individual data suggested that there were both positive and negative significant changes during each time period. It also revealed that there were no significant differences in improvement scores among patients categorised according to, length of time of implant use and under going rehabilitation. Patients who upgraded to use Fo F1 F2 Strategy showed significant improvements in performance than those who used only Fo, F2 strategy. Users who were categorised as having open set speech recognition at the three month interval had significantly larger improvement in scores than the group of patients who did not meet the criterion for open set speech recognition.

Brown, Dowell and Clark (1987) have reported the clinical results for twenty-four patients using the nucleus 22-channel cochlear implants. The speech processing strategy used, extracted the amplitude, fundamental frequency, and an estimate of the second formant frequency (F0F2) from the acoustic signal. CID every day sentences, in both live and recorded voice conditions were presented in two modes: auditory mode alone and audio-visual mode. Speech tracking procedure as described by DeFillippo and Scott (1978), was also used in audio-visual presentation mode. They observed continued improvements in the scores of the above tests in thirteen patients over a twelve month period. The average open set discrimination score (using the CID everyday sentences test) of these patients at three months post operatively was 16 %. Twelve months postoperatively the average score was 37%. The average improvement was 20% with the range of improvement varying from 0% to 44%.

Dorman et al, (1990) selected twenty seven patients from the data pool of patients who participated in the clinical study for premarket approval of the ineraid implant. Patients were included in this report on the basis of spondee recognition scores at one month, six to nine months, twelve to fifteen months, and twenty- two to twenty-five months post fitting. Approximately half of the patients received some rehabilitation in the form of audio cassettes and training a patient's spouse to engage in speech tracking. The patients were tested with the twenty-five words of the Spondee Recognition Test of the Minimum Auditory Capabilities test battery, in a free field condition at 70 dB SPL. The number of years of deafness varied from one year to forty-nine years. The speech recognition scores improved for some patients in the period between device fitting and one-month post fitting. But for majority of others there was large improvement in scores in the period between one month to six to nine months. Few of them showed improvements even after nine-month period. Using results of multiple regression analysis, they concluded that neither the magnitude of pre-implant residual hearing nor years of using a hearing aid predicts positive success of a cochlear implant.

Youngblood and Robinson (1988) reported the results of five patients, who were consecutively implanted with the Ineraid cochlear implant device. Patients were tested with the sound effects recognition test (SERT) and selected material from the minimum auditory capabilities (MAC) battery, in recorded voice presentation. They were followed up in one-month, three-months interval for the first year, and six-months intervals for the second year. The SERT was a closed-set test where as the MAC battery consisted of eight closed-set and six open-set sub tests. Patients underwent one to two hours of rehabilitation, once a week for the first ten weeks. All the patients showed a significant improvement in scores over all the tests and it increased up to nine-months post fitting. The improvement in scores ranged from 9% to 38%, over nine-months post fitting.

Gagne et.al., (1991) conducted a staggered multiple baseline repeated single-subject experimental design study to investigate whether, an intensive post-implant speech perception-training program designed specifically for cochlear Nucleus 22-channel cochlear implant recipients is effective. Subjects were four adults with a profound sensory-neural hearing loss acquired after the development of speech and language. The age ranged from seventeen years to sixty-four years. The testing schedule was such that the subjects were tested once before the surgery, and at three months intervals over a period of approximately twelve months post lilting. The following tests were included in the test battery: The consonant recognition test, The Medial Vowel test, The sentence understanding with out context test, and continuous discourse tracking. Each test was administered in three different sensory modalities: audio-only, visual-only, and audio-visual. All the subjects took part in an intensive aural rehabilitation program, according to their pre-assigned treatment schedule and it consisted of twelve, weekly three- hour sessions. The results indicated significant improvements in speech recognition abilities of sentences and spondees over the post fitting period, in the 'audio-only' mode.

Weston and Waltzman (1995) examined the relationship of time to cochlear implant patient performance and the effect of device design on patient performance over time. The subjects were the recipients of Nucleus22, Ineraid or 3M/vienna cochlear implants. The age range and the number of subjects is not reported. The test protocols were in five categories to check prosodic, lip-reading, phonetic, spondee recognition, and open-set discrimination characteristic improvements. The maximum scores varied for each category and as a whole it counts to 250. The subjects were studied at three-months, one-year and two-year post fitting. Results indicated that cochlear implant design has an effect on the improvement in performance over speech perception tests. The performance of Nucleus22 device users reached plateau sooner (an average of three months) than the other two models. But after two years there was no significant difference in performance between different device recipients. Ineraid and 3M/ vienna device users reached the plateau at two-years post fitting. The improvement in performance was seen in all the categories of the test battery.

Tyler and Summerfield (1996) considered the results of literature along with data from three groups of adult patients and one group of child patients implanted at the University of Iowa. Before implantation all the adult patients were profoundly, bilateraly, and post-lingually deaf. The group A consisted of 24 patients implanted with Nucleus22 channel implant systems using feature-extracting processing strategies (studied by Patrick and Clark, 1991). The group B consisted of 25 patients who received Ineraid systems of compressed analog strategy (studied by Eddington, 1980). The group C consisted of 28 patients who received the Clarion system (studied by Schindler and Kezssler 1993). Over 90% of the members of the group C, used their implants in the continuously interleaved sampling mode. The duration of deafness varied from two to forty-eight years. For groups A and B the word recognition in sentences (Iowa sentence test) and consonant recognition in nonsense syllables were plotted with respect to duration of deafness. These scores were obtained after thirty-months usage of implants. The results indicated that the longer a patient has been profoundly deaf, the poorer the performance with the implant. The performance of the three groups over Iowa sentence test was analyzed over five-year post fitting. For all the three groups the performance improved significantly over the first nine-month usage of a cochlear implant.

Considering all the three groups together about 80% of patients showed individually significant improvements in speech perception performance with time after implantation. The members of groups A and B (second generation cochlear implant system users) showed an improvement in scores over two or three years post fitting. The group C members (third generation cochlear implant users) displayed more rapid learning than those of groups A and B.

Loeb and Kessler (1995) analysed the pre operative and three, six and twelve month post operative scores of forty six patients fitted with the Clarion device. The patients ranged in age from twenty to eighty one years. 85% of the subjects used monopolar continuous inter leaved sampled pulse (CIS) strategy and the rest used continuous analogue mode (CA). Speech perception tests included the open set CID sentences and the open set North Western University (NU-6) monosyllabic words. They have developed a comparative ratio called "Improvement Rate Factor (IRF)" they have extracted the IRF's for the three test periods. Maximum values of IRF's for nineteen subjects were observed at the third month session only. The remaining attained their maximum IRF'S by the sixth month session.

$$IRF = \frac{\text{CID (3months) - CID (Pre-op)}}{\text{CID (12 months) - CID (Pre op)}}$$

George et.al, (1995) Presented the preliminary findings of the new Spectra 22 speech processor in first time cochlear implant users. There were eleven subjects, who were postlingually deaf and greater than eighteen-year old. The patients were tested at two weeks, one month, three months and six months after switching 'ON' the device. The test battery comprised of monosyllabic (CNC) word recognition test, C1D sentences, City University of New York (CUNY) sentences and environmental sound tests. There is no statistical analysis done for the results obtained. By observation, they said that each of the word and sentence tests showed a general trend of a small, steady increase in scores over time up to the three month point. But the scores at six-month period were lower than that at the third month scores. The authors could not reason for this observation.

Gray et.al., (1995) Have studied fifteen adult, Ineraid cochlear implant users over eighteen months period . All were post lingually deaf with profound hearing loss. Performance was tested in lip reading, implant only and combined lip reading and implant notes using Boothroyd word lists. Bamford-Kowal-Bench(BKB) sentences and connected discourse tracking. Assessments were made after ten hours of training and again at nine and eighteen months post-implantation. A profile of implant performance over time showed that after ten hours of training, twelve of the fifteen had some speech discrimination in the implant only mode for all the three tests. When using their implant only mode all fifteen showed significant improvements in the performance over all the tests. Between nine and eighteen months there was a slight trend toward the improvement in implant only mode performance. So most of the benefit had occurred in the period between ten hours to nine months.

Archbold, Lutman and Marshall(1995) developed the "Categories of Auditory Performance," (CAP) and conducted a study to examine the properties of the CAP and its use with the fifty-three children who were deafened below the age of three years. The CAP consisted of eight indices of performance, ranging from no awareness of sound to using the telephone. Children are studied prior to the implantation, immediately at initial tuning, at third, sixth and twelfth month post tuning and there after annually, for three years. Before implantation only two of the children showed awareness of environmental sounds. Immediately after initial tuning, all children were aware of environmental sounds and 50% responded to speech sounds. One year after implantation, majority (91%) discriminated speech sounds, but were unable to understand phrases and conversation. 81% had achieved understanding of phrases by the end of the second year. Almost all were able to understand phrases or conversation without lip-reading by end of three years. The type of cochlear implant, and the speech processing system are not mentioned.

III. EVIDENCE FROM AUDITORY DEPRIVATION STUDIES

Hattori (1993) studied the effect of monaural amplification on children with losses of moderately severe or profound sensory-neural hearing loss (age ranged from four to five years). He compared the non-sense syllable recognition scores of two groups of children. The first group (seventeen children) wore monaural amplification. The second group (eighteen children) wore either binaural amplification or monaural hearing aid that was alternated between ears on a weekly basis. The period between the initial measure and the final measure ranged from two to twenty-three years (mean being fifteen years). They were tested under headphones for the same non-sense syllable recognition. The results showed an increase of twenty percent in recognition score in monaural aided condition only. The other two (binaural or monaural alternated between ears) conditions did not show any significant change over time. The base line speech recognition performance measures were not obtained at the time of fitting the hearing aid. There is no way of Knowing whether or not hearing was symmetric before amplification. The effect of development of speech language skills on the scores is also not ruled out.

While finding the effects of monaural versus binaural hearing aids Silman et. al; (1984) compared speech recognition thersholds, and speech recognition scores in two groups of adults with bilateral hearing losses. Subjects consisted of forty-four monaural hearing aid users and twenty-three binaural hearing aid users(mean age being fifty-eight years).They were tested using CID. W-22 PB words at 40 dB SL (re: SRT) under head phones over four and five years since from the time of fitting the hearing aid. There was no significant difference in the word recognition scores over the initial and final test sessions in the aided ear.

Silverman (1989) did a retrospective, longitudinal case studies to examine the speech recognition scores over an eight to twelve year period, in two-monaurally fitted adults with bilateral sensory-neural hearing impairment. Their ages were fifty-four, and eighty two years. He has used CID W-22 phonetically balanced word list at 40dB SL (re: SRT). The subjects were tested under headphones. There was statistically no significant difference in the aided speech recogniton scores in the aided ear, even though they were studied over eight to twelve year period.

Table.RV, 1. Summary of studies on acclimatization

SL. NO	STUDY	N	NEW/EXP	MON/BIN	STIM.DELIV	DEP.MEAS	TIMETABLE	RESULTS
1.	Watson &Knusdon, 1940	1	New	Mon	Headphones	SRS	10-12 weeks	Y. large improvement (50%) after 10-12 weeks
2.	Malinoff & Weinstein, 1989	25	New	Mon	HA	HHIE	3.12,52, weeks	N, large improvement after 3 weeks, which decreased later on
3.	Gatehouse. 1992	4	New ?	Mon	HA& Headphones	% CNC (FAAF), + 10SNR,65db	12 weeks. 0-6 weekly. 8-12 biweekly	Y, after 4weeks. 10-15% increase
4.	Cox &Alexander, 1992	10-17 (12)	8 New. 9Exp.	9 Mon, 3 Bin	HA	% CST. +7. +2 SNR, 55.64db. T. PHAB	10 weeks	Y ?. 4-5% & dependent on listening conditions (essf)
5.	Murlow et al., 1992	192	.	Mon	HA	HHIE, Denver Quick scale	16, 32, 52 weeks	N
6.	Taylor. 1993	58	New.	37 Mon, 21 Bin	HA	% CNC. Q. + 10 SNR, 62db.HHIE	3.12, 24. 52 weeks	N.HHlh large improvement after 3 weeks, decreased later on
7.	Bentler et al., 1993a	65	39 New, 26Exp.	55 Mon, 10 Bin	HA	% SPIN. + 8 SNR, %NST,Q, + 5SNR, 65-75db	4, 12, 24. 52 weeks	N
8.	Bentler etal., 1993b	65	39 New, 26Exp.	55 Mon, 10 Bin	HA	HPI-38, Speech commn subscales	4,12,24.52 weeks	N?, "Speech in Quiet only"
9.	Gatehouse, 1993	36	Exp	Mon	HA	% CNC (FAAF), + 7 SNR, SVT in noise	0, 8,16 weeks use of iproved HA(NALVs NHS)	Y. NAL 3-5% orldb SNR better than NHS by 8week
10.	Arkis & Burkey, 1994	105	New?	70 Mon, 35 Bin	Headphones	% CNC, Q, 30dbSL	Meantest-retest interval of 33 weeks	Y, 5% increase for Mon & Bin aided
11.	Horwitz, 1995	26	13 New, 13 Exp (control)	Mon	HA	%NST, + 20SNR,70db. PHAB	0, 3, 6, 10, 14, 18 weeks	Y. New users, 7-8% increase, 0-8 weeks. NST & PHAB
12.	Humes et al., 1995	20	10 New. lOExp.	Bin	HA	%NST, Q. 70db; %HINT, + 7 SNR, 70db; HAPI,HHIE	0,1,2,4.8,12, 24 weeks (HINT through 8 week only)	N
13.	Cox etal., 1995	27	22 New, 5 Exp (control)	Mon	HA	% CST,+1, or+ 3 SNR, 63db;%SPAC,Q,63db	0,12 weeks (CST); 0,3,6, 9,12 weeks	Y, 4-5% increase after 12 weeks for group, but onlv 3 of 22 SS.

- *i*

1—1							(SPAL)	
14	Saunders et al..(1997)	48	24 New. 24 Exp (control)	Mon	HA	%CID(W-l)test,% HINT	0, 30,60. 90 days.	N
15.	Horwitz & Turner (1997)	26	13 New. 13 Exp (control)	Mon	HA	%NST, PHAB 55-65db, Adjustment of Hearing Aid gain	0,18 weeks	Y,7% increase after 18 week
16	Lippy, Burkey & Arkis (1998)	24	24 New	Mon	HA	%WRS	Once in every 6 months for 2 vears	Y, 16.2% after 2 years

N = Sample size;
New/Exp = New or experienced hearing aid users;
Mon/Bin = Monaural/Binaural fittings;
Dep Meas = dependent measure of acclimatization;
SNR = Signal to noise ratio in db;
Q = Quiet;
Timetable = Test interval used in study;
Acclim? = Presence/absence of acclimatization effect (Y= Yes, there was a significant effect; N= No, there was not a significant effect;
Y? =Multiple measures with most, but not all, suggesting significant effect;
N?= Multiple measures with most, but not all, suggesting no significant effect;)
HA = Hearing Aid.

METHOD

The aim of the study was to verify the existence of the auditory acclimatization effect and also to check whether DL1 can demonstrate the acclimatization effect. The methodology is described in three sections :

Subjects, Procedure and the Measures.

I. **Subjects** :

Three subjects participated in the study. All of them were new to hearing aid use, and the subject characteristics are described in the table M. 1.

Table-M.l : Subject characteristics

	Age / sex	Hearing loss (degree & type)	Duration of hearing loss	Etiology	Hearing aid usage
CASE.l.	66yrs/M	Bilateral severe SN hearing loss	2-3 years	Presbycusis	Monaural (right)
CASE.2.	79yrs/M	Bilateral Moderate SN hearing loss	5 days	Meniere's disease	Monaural (right)
CASE.3.	80yrs/F	R- Moderately severe hearing loss L- Moderate SN hearing loss	7 months	Presbycusis	Monaural (left)

They were selected on the basis of the following criteria :

(a) Should belong to the age range of thirty to seventy years,

(b) Should have acquired hearing loss post-lingually in both the ears.

(c) Should have a puretone-average (average of pure tone thresholds at 500Hz, lOOOHz and 2000Hz) of greater than 25dB HL in both the ears,

(d) Should have sensory-neural hearing loss in the aided ear,

(e) Should be a first time hearing aid user, and be available for the follow-up (as described in the next section),

(f) Should have no progressive medical conditions, that affect data collection, and

(g) Should be verbal and a native speaker of kannada language

All of them were using the linear hearing aids, prescribed by the audiologists after a detailed hearing aid selection procedure. The hearing aid characteristics and settings are described in the Table M.2.

Table-M.2 : Hearing aid characteristics

	HFA SSPL 90	HFA FOG	Frequency range in Hz	EIN	THD	Prescribed volume / tone
Model-1	127 dB	41.1 dB	222-4500	20 dB	.8%	ll/2/N
Model-2	124 dB	43.3 dB	300-4300	19.3 dB	1.1%	3/N
Model-3	126 dB	42.6 dB	250-4500	22.1 dB	1.3%	2/N

II. The measurement procedure for hearing aid benefit

Hearing aid benefit is defined as the improvement in "hearing ability" due to the hearing aid (Turner et. al., 1996). Thus it is the difference in performance measured in aided and unaided conditions in a given test trial. The aided and the unaided measures of hearing ability were obtained in a free field condition, where the subject was seated comfortably in a chair which was located one meter away and 45° angle from the loud speaker.

Both the non-speech and speech tests, described in the next section, were administrated through a calibrated diagnostic audiometer (Madsen 0B822). The speech material was delivered in live-voice.

The testing was done in the two-room sound treated set-up, where the ambient noise levels were controlled such that there was always a signal to noise ratio of at least lOdB SPL (Arlinger, 1994).

After the subject was selected he/she was given a description about the study and his/her participation was made voluntary. The testing was carried out, according to a single-subject "time-series design (Hegde, 1994) described below :

X	O1	O2	O3
****	****	****	****

Where, "X" refers to the measures taken at the time of hearing aid fitting and O1.3 refer to the post-fitting measures which included both aided and unaided measurements. The dotted lines indicated that, the subject wore the hearing aid throughout the experiment. The four trials were :

X : At the time of fitting a hearing aid

01 : One-month post-fitting

02 : Two-months post-fitting

O3 : Fourteen-weeks post-fitting

III. Hearing Aid Benefit Measures

The aided and unaided scores of two speech and two non-speech tests were compared with each other in all four trials. The tests were :

1. Pure tone thresholds
2. Speech recognition thresholds
3. Speech identification scores and
4. Difference Hmen for intensity.

1. Pure tone thresholds

The pure tone air conduction thresholds were obtained for the octave frequencies ranging from 125 Hz to 8000 Hz, according to the Carhart-Jerger's modified Hughson-Westlake method (as cited in Silman and Siverman, 1991).

The subjects were instructed as - "You are going to hear a tone which will become fainter after some time. Every time you hear the tone, raise your finger. If you are very sure of the tone being heard, then only raise the finger otherwise put it down".

The minimum intensity where the subject responded 2-3 times correctly, was taken as the pure tone air conduction threshold, for a particular frequency. Some times, verbal responses were also considered as correct responses.

2. Speech Recognition Threshold (SRT)

It is the lowest hearing level at which a person correctly recognises the speech stimuli 50% of the time (Silman and Silverman, 1991). The test material contained 40 paired-words in Kannada , developed by Rajashekar (1976). The speech recognition thresholds were elicited according to the procedure recommended by ASHA, 1979 (as cited in Silman and Silverman, 1991).

The subject was instructed as- " You are going to hear a few words, and you have to repeat them after me ".

3. Speech Identification Scores

It refers to the percentage of the monosyllable identified by the listener at the most comfortable level for speech. Initially, speech at a level of SRT + 40dB was presented and the subject was asked whether it is comfortable or not. If it was comfortable then 40 monosyllables, developed by Mayadevi 1974), were presented at that level. If it is uncomfortable, then the level was lowered to a level where it is comfortable, and testing was carried out.

The subject was instructed as " You will be hearing some speech sounds, repeat them after me ". The number of monosyllables identified correctly were compared against 40, to draw the " Percent correct score".

IV. **Difference limen** for **intensity (DLI)**

It is the change in the intensity in dB, which results in a just noticeable loudness change (Silman and Silverman, 1991). This test is Included by considering the recommendations of Byrne and Dirks (1996) to evaluate auditory acclimatization. The DLI thresholds were elicited for 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz at lOdB SL and 40dB SL (re : PTA) carrier tone levels.

The subject was instructed that -" Listen to the steadyness of the tone. If it is not steady, flicker your finger ; if is steady, don't flicker". The lowest modulation level for which he flickered his finger two out of three times at a given level of carrier tone of given frequency, was considered as the DLI at that level and frequency.

The data was collected for each subject and tabulated. Statistical analysis was also applied.

RESULTS AND DISCUSSION

Mean data is represented in the figures where the dynamics of hearing aid benefit (difference between aided and un-aided scores) is traced over time for different tests.

Since ANOVA (analysis of variance) requires just replication (minimum of two subjects), a 1-Way repeated measures ANOVA was done for all the results of tests.

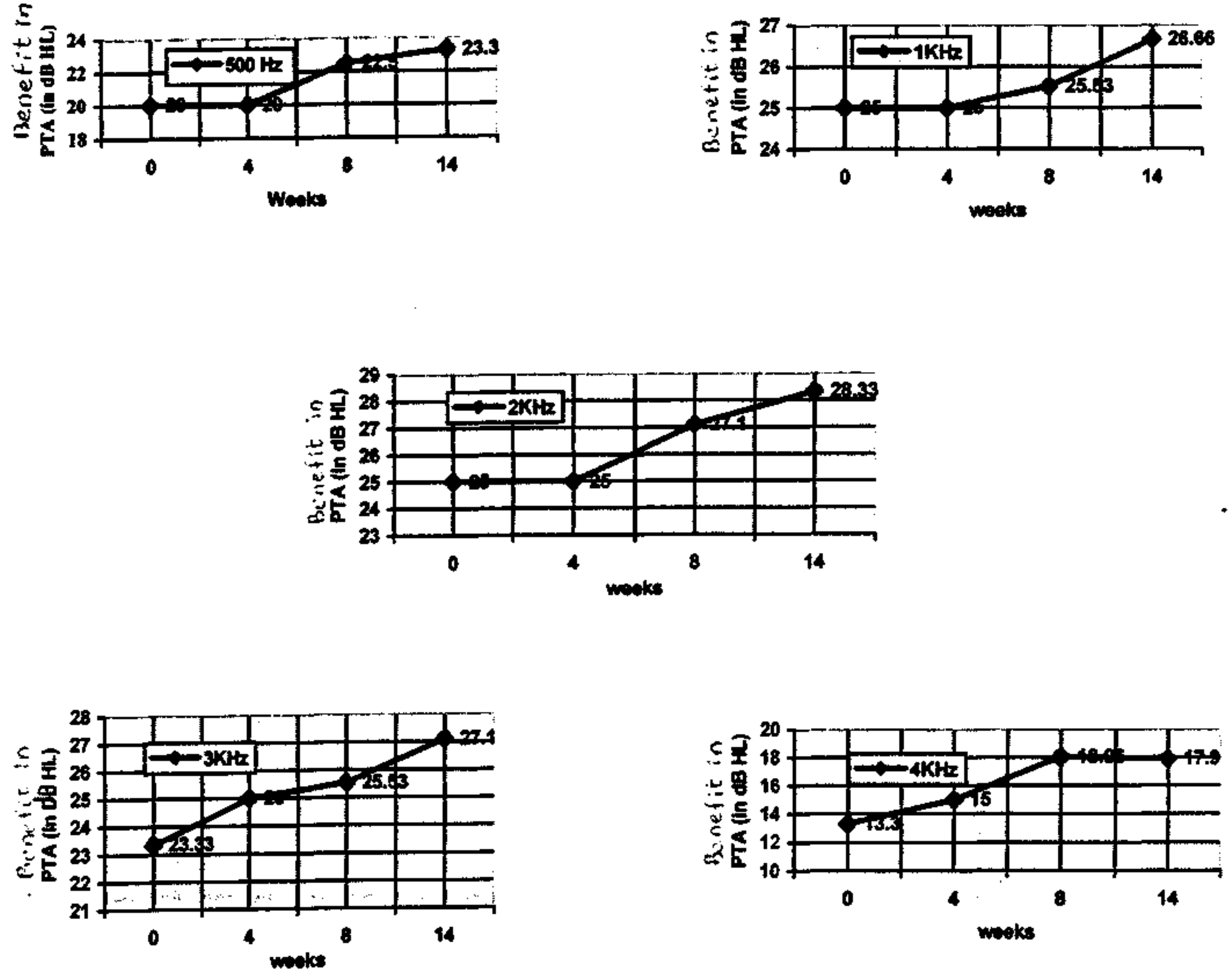
Insert **Fig-R.1.** : Mean Benefit for Pure Tone Thresholds

Pure tone threshold benefit :

The results of ANOVA showed no significant difference between groups and within groups at 500 Hz ($F = 0.158$; $p = 0.922$), 1000 Hz ($F = 0.033$; $p = 0.991$), 2000 Hz ($F = 0.068$; $p = 0.975$), 3000 Hz ($F = 0.040$; $p = 0.989$) and 4 kHz ($F - 0.667$; $p = 0.596$). Here the terms 'between groups' refers to the different frequencies tested and 'within group' refers to different subjects at a given frequency. Similar meaning is associated when the terms are used elsewhere.

Though there was a mean improvement it was statistically insignificant. Thus the present study does not support the results of a follow up study done by Nagaraja, Mali and Joshi (1994). Their study compared the hearing aid benefit at the time of fitting with that after six months. Though there is difference between the studies in terms of the duration of the follow up the present study does not support Nagaraja, Mali and Joshi's study because it is said that acclimatization saturates after 3 months, post fitting. Other possible

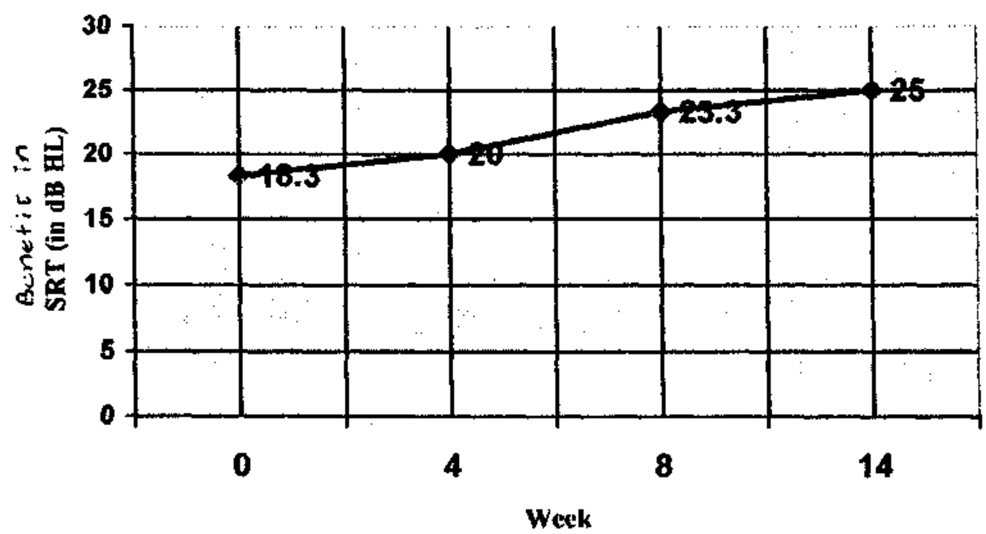
Fig-R1 : Mean benefit in pure tone thresholds over time



differences are that their study did not report the method of fitting the hearing aids (direct Vs indirect), the nature of the output (linear Vs non-linear) etc. Other studies coated in the literature have not compared pure tone thresholds over a period of time (for eg. Gatehouse, 1992).

SRT Benefit:

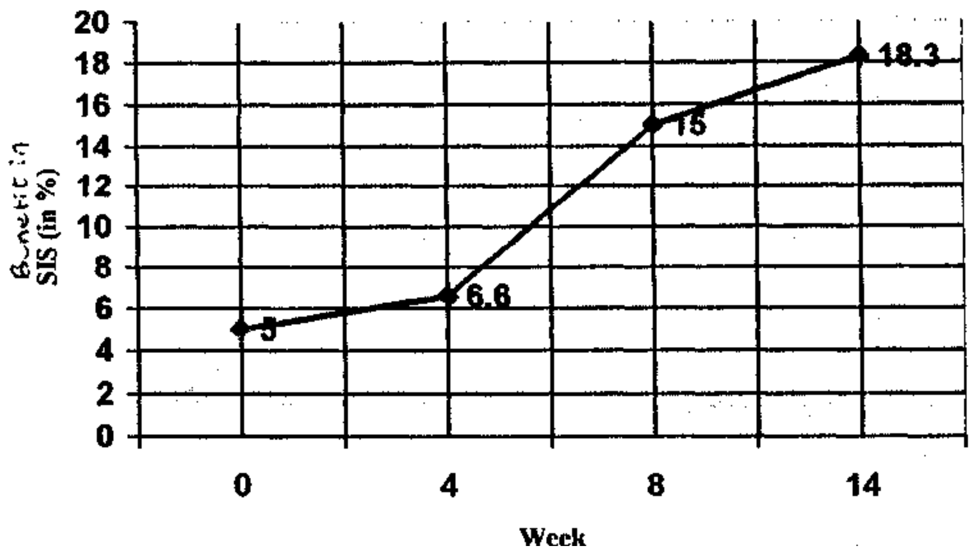
Fig-R2 : Mean benefit in SRT



Similar is the case with SRT 's the present study did not show any statistically significant changes in SRT benefit. Thus it supports the results of Saunders and Cienkowski's (1997) study, where they could find small but insignificant changes in SRT. From the results of the present study and several other studies (for eg. Saunders and Cienkowski ,1997) it may be said that thresholds are less affected by long term usage of a hearing aid, and so, may be given less preference in a test battery to evaluate auditory acclimatization.

Speech identification scores benefit:

Fig-R3 : Mean benefit in speech identification scores



The other measure used in the present study was speech identification scores at the most comfortable level. The result showed the significant improvement with time which ranged from 5 to 18 %. The ANOVA results showed a significant difference both within and between groups over a period of 3 months ($F = 4.262$; $p = 0.045$). A post hoc test was done to find out when was the significant change occurring. This indicated that between the 4 to 8 and 8 to 14 weeks there was a significant change occurring in speech identification scores. Thus the present study supports many other studies (for eg. Gatehouse, 1992) who have shown the existence of acclimatization. So it may be said that speech, identification scores are better able to trace the auditory acclimatization. However, the benefit is large in the present study which can be attributed to several reasons :

(1) Suitable amplification across speech frequencies (300 to 3kHz),

(2) Effective counseling,

(3) Duration of daily usage which is almost 8 hrs per day,

(4) Narrow age range of subjects,

(5) Relatively unaffected discrimination ability,

(6) Nature of the output (which is linear in the present study), and

(7) Level of presentation of the material etc.

One or several of the above mentioned factors are different in different studies.

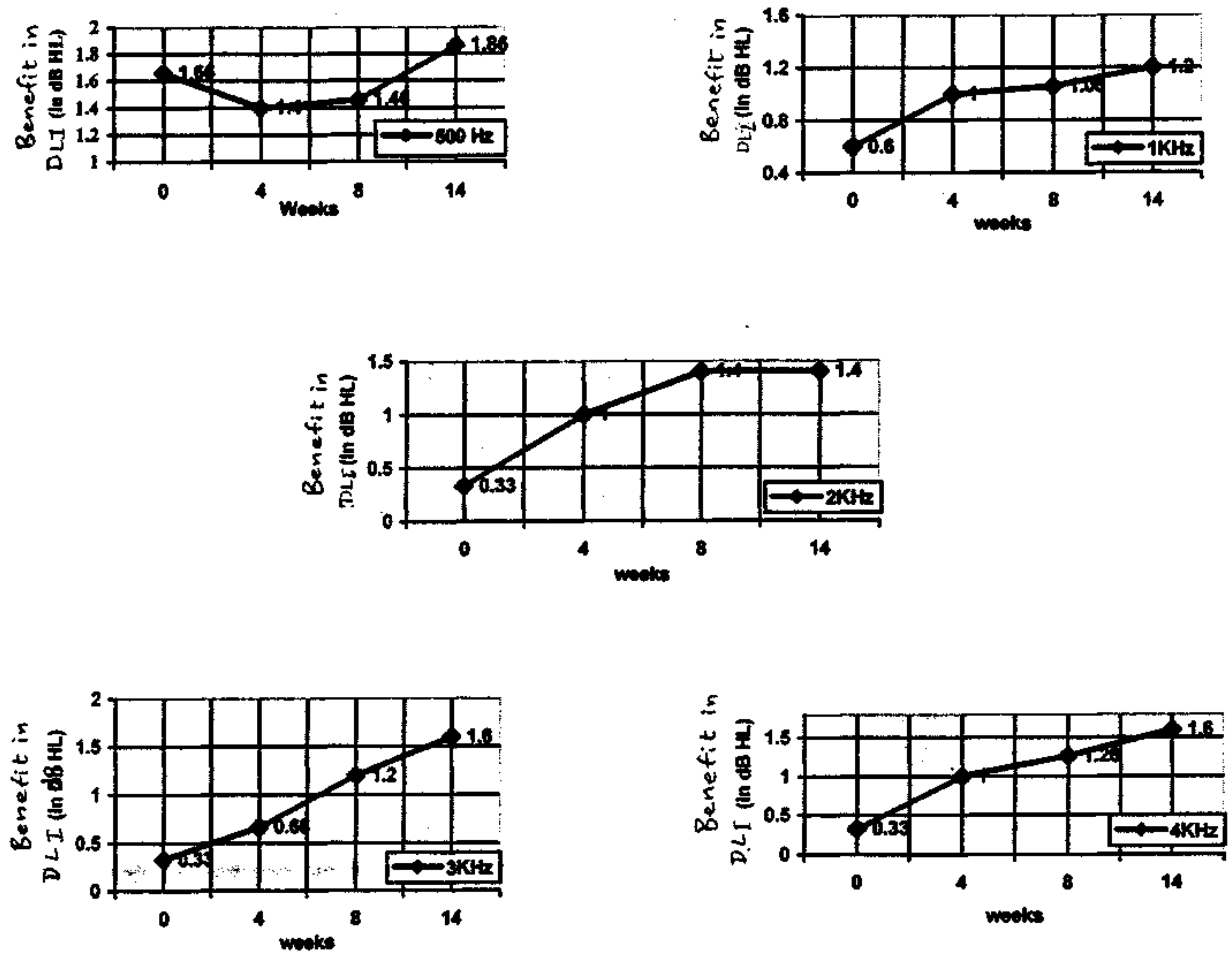
DLI benefit:

Though DLI has been used to differentiate cochlear Vs retrocochlear lesions, the present study used it to trace the effects of acclimatization on intensity discrimination ability.

Insert **Fig-R4** : Mean benefit in DLI

A three way repeated measures ANOVA has been carried out since there are three variables (carrier tone level, frequency of the carrier tone and the week of measurement) . There was a significant difference between the two carrier tone levels that is 10 dB SL and 40 dB SL ($F = 10.543$; $p = 0.002$), different frequencies of carrier tone that is 500 Hz, 1 kHz, 2 kHz, 3 kHz and 4

Fig-R4 : Mean benefit in DLI over time



kHz (F = 5.548 ; p = 0.001) and across the weeks (F = 15.511 ; p = 0.000).

Two post hoc tests have been carried out for performance across frequencies and performance across weeks. The result indicated that DLI varied maximally for 500 Hz ; further for all the frequencies the significant variation in DLI was seen between 0 to 4 weeks and 8 to 14 weeks. But there was no significant difference between 4 to 8 weeks.

Since two levels of the carrier tone (lOdB SL and 40 dB SL) were used, and both of them showed a significant difference in DLI ,it may be inferred that both the levels are equally advantageous. This is said by keeping in mind Gatehouse's hypothesis (1989) and the the procedures used by several authors (for eg. Gatehouse, 1992) who emphasized that supra threshold presentations of the materials in the aided ear are preferable. The post hoc test results which showed 500 Hz was more effective is not in accordance with Robinson and Gatehouse, (1995) study which showed a significant improvement of DLI at high frequencies (3 kHz). This may be because of the less number of subjects used in the present study. Hence DLI can also be used as a test to evaluate acclimatization effect.

Hearing aid benefit is frequently defined as the difference between a patient's performance with and without hearing aid. However, there is a disadvantage in using this single number metric to describe hearing aid benefit. For. eg. if a patient's unaided scores decline over time and the aided scores remains stable over the same period, benefit will show an increase. This is clearly a different sort of acclimatization that would be observed if increases in benefit arc duo to increases in the aided scores over time, even though both cases show an increase in benefit. Thus three types of auditory acclimatization can be evidenced from retrospection. They are :

Type-1 : The unaided scores remains stable, where as the aided scores improve.

Type-2 : The unaided scores deteriorate, where as the aided scores remain unchanged .

Type-3 : The unaided scores deteriorate, and the aided scores improve.

It is the type-1 acclimatization that is demonstrated in the literature (for eg. Cox and Alexander, 1992) and in the present study. But it is possible that types 2 and 3 are also existing. To differentiate between these three types, it is necessary to examine not only the difference but also the raw scores that are used to derive the difference the amount of benefit shown by today's, commercially available hearing aids is related to the problems in defining the hearing aid benefit.

Two mechanisms, namely learning and plasticity have been used to explain the dynamics of hearing aid benefit. These two mechanisms have successfully explained the auditory acclimatization and the major factors affecting it.

(A) Perspectives of Learning :

Robinson and Summerfield (1996) proposed that acclimatization may be viewed as a long term learning. They classified this type of auditory learning in to : procedural, stimulus, and task learning : which are related to the physical manipulations the experimenter might seek to control.

Procedural learning refers to the learning surrounding the response demands of the task for eg. Horwitz (1995), in her study of acclimatization of new hearing aid users employed experienced hearing aid users to control for effects associated with learning, the requirement of the task, the experimental setting and other procedural demands. These experienced hearing aid users were not provided with any new acoustic information but were asked to participate in the experiment to control for procedural learning effect that may occur in any experiment.

Stimulus learning refers to the learning of specific features of the stimulus set. Acclimatization is a good example for stimulus learning. It is specific to the ear of aiding, as well as to the frequencies and levels normally provided by the hearing aid (Gatehouse, 1992 ; Robinson and Gatehouse, 1995). Acclimatization, a kind of stimulus learning, has two phases. The first phase is characterised by the " immediate benefit ", such as the degree of benefit in speech identification obtained immediately after fitting a hearing aid. The second phase occurs over longer time course and represents the learning that occurs after fitting a hearing aid or switching on a cochlear implant. This is referred to as "subsequent benefit". The difference in performance between the immediate and subsequent benefits from a hearing aid is the " extent of learning ". Rate of learning refers to how quickly the plateau of subsequent benefit is reached, which was described as acclimatization period in the acclimatization literature. Robinson and

Summerfield (1996) have also opined that modulators of learning are likely to contribute to these individual differences and may contribute to the variability in the size of acclimatization effects observed in different studies. They also determined the rate and extent of learning resulting from provision of the hearing aid or cochlear implant.

Task learning is an important determinant of training because the task selected by the experimenter shapes the procedural and stimulus learning experienced by the listener. For eg. an identification task (was the word ' sue ' or ' shoe ' ?) is likely to result in different procedural and stimulus learning than a discrimination task (are the words ' sue ' , ' shoe ' the same or different ?). Listeners are encouraged to learn between category differences with identification task, where as they learn fine within category differences with the discrimination task. Hence the task it self can determine what kind of learning occurs.

Robinson and Summerfield (1996) after observing the results of several studies (for eg. Lacroix and Harris, 1979) drew the following explanation. Hearing impaired listeners may develop supra normal abilities in interpreting low frequency speech cues. Over a long period of time they may learn to use low frequency cues such as prosody more effectively than normally hearing listeners given an immediate high frequency loss through low pass filtering. This phenomenon is seen even in our daily clinical practice, where a low frequency fibers get acclimatized, soon after aiding the impaired ear, that result in improved scores of auditory performance. Even though Robinson and Summerfield 's observations were over the unaided sensori neural hearing impaired ; with the help of results of several acclimatization studies (for eg. Gatehouse and Killion, 1993) the observations can also be extended to the aided sensori-neural hearing impaired ears. However, Doherty and Lutfi (1995) reported that unaided sensori neural hearing impaired persons attached most perceptual importance to the mid frequency component of a complex signal. Here the subjects had high frequency sloping hearing loss. So this result may not be generalized to other patterns of sensori neural hearing impairment. If an unaided sensori neural hearing impaired has achieved supra normal or normal abilities in the low and mid frequencies, what is it learning after getting aided over time ? Answers to this question has been attempted by several plasticity studies (described in the next section) and few retrospective observation (Gatehouse and Killion, 1993). They indicate that the high frequency nerve fibers through out the auditory system take some accomodation time to learn to process high frequency information. So, over a period of time high frequency cues are learnt, but this is effected by several factors called as modulators of learning.

Modulators of learning :

In the review of literature it is seen that there exist large individual differences as evidence for acclimatization effect. These differences are also apparent in other experiments on auditory learning, and they may be a general characteristic of learning. Robinson and Summerfield, (1996) suggested that modulators of learning are likely to contribute to the variability in the size of acclimatization effects observed in different studies. Many such modulators are described here;

(1) Duration of hearing loss : This is a general term for a number of potential learning modulators, such as loss of memory for sounds in general and for speech in particular, loss of spiral ganglion cells and nerve fibers and loss of central plasticity. This modulator may be important in explaining the acclimatization seen in severe to profound hearing loss cases. This is also important in explaining the success with cochlear implant (Gtantz et al,1993;Tyler and Summerfield,1996;Summerfield and Marshall, 1995). If the duration is longer it may take longer time for the learning to take place and the extent of learning may also be limited.

(2) High frequency gain: More amount of gain leads to more learning , when the frequencies above 3 kHz are also amplified. This may not be true with the hearing impaired whose thresholds are less than 40 dB HL. But for people with more than moderate degree of hearing loss, high frequency (> 3 kHz) amplification significantly improved the auditory performance in terms of improvements in speech identification scores (Hogan and Turner , 1998). It is also said that low frequencies get acclimatized at the time of fitting hearing aid itself where as the higher frequencies take longer time. This indicates a need for high frequency amplification. But Cox et. al., (1996) could not prove this in their experiment where they had monitored the insertion gain, and found no significant difference between the performances of hearing aid users with and without high frequency amplification

(3) Severity of hearing loss : Gatehouse, (1994) has examined the relative contribution of this factor to the speech identification performance or eventual benefit form a hearing aid. For a conventional speech identification test, he

showed that the severity of hearing loss explained approximately 25 % of the variance that is more the severity less the eventual benefit. This measure may be predictive of the rate and extent of learning and therefore, may explain individual differences found in the literature.

(4) Psychoacoustic ability : Psychoacoustic measures such as frequency and temporal resolution may also be related the speech identification performance of the hearing impaired (Glasberg and Moore, 1989 ; Tyler et. al., 1982). Gatehouse (1994) found that temporal and frequency resolutions explained 4 % and 3% of the variance, when examined for a conventional speech identification test.

(5) Powers of attention and short term memory for sound : Gantz et. al., (1993) showed that accuracy of performance on a task requiring rapid visual information processing was positively correlated with post operative benefit from implantation. This test measured the ability to detect triads of digits in rapidly changing visual sequence. This cognitive ability, which involves attention and short term memory, might also explain individual differences in the subsequent benefit obtained from hearing aids.

(6) Personality characteristics : These are also likely to be potential modulators of learning associated with cochlear implants and hearing aids. For eg. patients who report that they are active and informed about their health care compared with those who are inactive and trusting, showed more subsequent benefit from cochlear implant (Gantz et. al., 1993). Gatehouse, (1994) reported that the level of anxiety among hearing aid users explained

4% of the variance associated with the eventual benefit using a speech identification measure.

(B) Perspectives of Plasticity : In the jargon of neuroscience, the term 'plasticity' has been used to describe a variety of alterations in the physiological and / or the anatomical properties of neurons in the Brain. Mechanism of plasticity may involve synaptic changes that occur very rapidly or ' rewiring ' of neural circuits with a time course of weeks or months. Examples of neural plasticity include neurobiological changes associated with environmental variations during development, recovery from Brain injury, damage to peripheral sensory receptors, sensory experience and various types of learning. The last three are most relevant with respect to hearing aid use, and acclimatization.

Willott (1996) indexed three types of auditory plasticity :

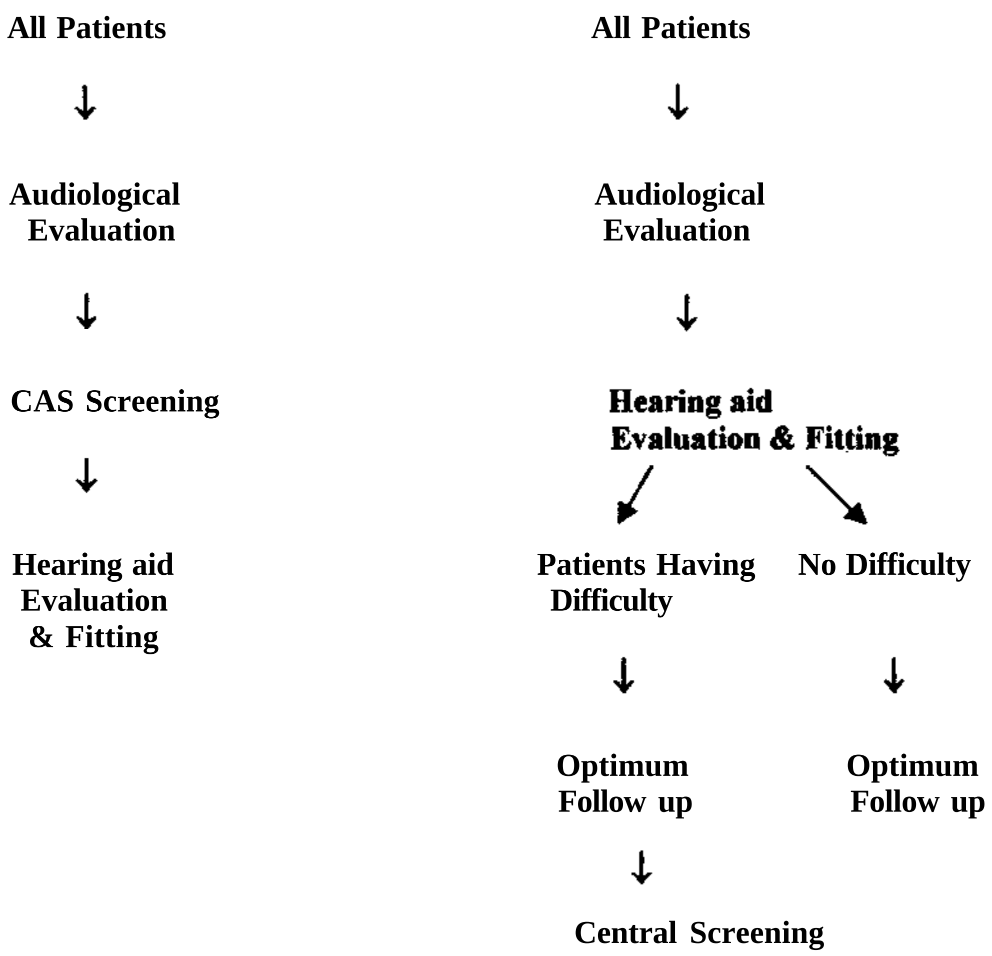
(a) Plasticity induced by the removal or attenuation of auditory input to the central auditory system (CAS) : - Several areas of research on plasticity suggest that peripheral hearing loss may induce important changes in the response properties of CAS neurons, and it is possible that these could have an impact on hearing aid use. Potential changes include : reorganization of sensory maps caused by damaged to a portion of the peripheral receptors, reorganization of neural responses with respect to the laterality or spatial location of sound and, the synaptic or circuit alterations associated with attenuation of peripheral sensory input to the brain. Research also suggest that these physiological changes may result in behavioral changes. Plasticity of interactions between excitation and inhibition evoked by binaural stimuli would be expected to have an impact on perception as well, and these might be particularly important with respect to deprivation effects associated with monaural hearing aids.

(b) Plasticity induced by reproduction of sound by hearing aids :- This wood entail the modification or a reversal of hearing loss-induced plasticity that has already occurred. The effects of hearing aid in hearing impaired, depends on whether the hearing loss-induced plasticity has positive (change in critical frequency of neurons) and / or negative (degeneration of neurons) effects. If there are any positive effects in a hearing impaired the hearing aid may have negative effects, atleast initially, by distorting the relationships between acoustic stimuli and auditory responses that the CAS has come to use to good advantage. For eg. a hearing impaired person with positive effects of plasticity induced by hearing loss, is fitted with a hearing aid which makes the previously inaudible frequencies audible, there will be competition for the old neurons responsible for the perception of reintroduced frequencies, that presents new problems with neural coding of sounds. If such were the case reversibility of Plasticity is important, if it does not occur the hearing aid may be counter indicated, but if occurs acclimatization can progress. It is also shown that the monaural stimulation leads to bilateral plasticity changes in the Brain.

(c) Plasticity induced by synaptic or other changes associated with learning processes before and / or after hearing aid use :- Experiments in classical conditioning showed that the generalization of a conditioned stimulus can be made over a range of stimuli. This is similar to that in the alteration of frequency maps by cochlear damage. Alterations of representational maps can be obtained with both classical and operant conditioning techniques. This is what is happening in stimulus learning where a set of stimulus characteristics can be learnt resulting in a sensory map in CAS.

Thus plasticity may help us in understanding that the hearing aid when employed with a hearing impaired person, may succeed in altering hearing impairment-induced plasticity , thus a path for acclimatization is formed, but if fails, it has deleterious effects on speech perception. As on one side, the hearing aids have central deleterious effects, other side they also have negative effects on the peripheral auditory system. This may be seen when a hearing aid is producing over amplification at one or more frequencies ; and when outer hair cells are intact has in auditory neuropathy cases. In the latter case, a hearing aid providing amplification (according to calculations by prescriptive formulae or by direct methods) on prolonged jusage may damage intact outer hair cells, which results in further deterioration of the speech perception. It is also possible that both the positive and negative effects are seen, in that case the effects that are dominating will determine the success of the hearing aid. The plasticity research mainly involved the animals and it is presumed that there are no biochemical changes between the animal (mostly the rats) cortex and human cortex. Based on these assumptions several of the above conclusions are drawn. Willott (1996) concluded that the plasticity is not only determined by the hearing aid usage but also several factors such as modulators of learning, neurochemical composition, intelligence etc. may play a major role.

From the studies on learning, plasticity and acclimatization it can be inferred that the auditory acclimatization is a cortical phenomena. Through the evidence from the literature (Nagaraja, Mali and Joshi, 1984) and experience of the present investigator, it cam also be said that it is difficult to have more number of subjects for a follow up study in the Indian scenario. However, acclimatization in hearing aid users has to be made clinical apart from being studied, that requires a follow up. This problem of follow up can be solved by changing the clinical procedure of hearing aid fitting. The modification can be made by introducing a central auditory screening test (sensitive for cortical functioning) or by giving an optimum follow up period (modified versions of Mustek and Baran's, 1996, scenarios), which are suitable for Indian conditions.



In both the above scenarios central screening has to be made in both free field (aided) and unaided conditions . The plausible results and interpretations of central screening are :

	Central Screening		
	Aided	**Unaided**	**Interpretation**
Patient	Passed	Passed	Hearing aid is suitable
Patient	Failed	Passed	Hearing aid is not suitable
Patient	Failed	Failed	Not a candidate for hearing aid

SUMMARY AND CONCLUSIONS

The hypothesis that the hearing aid users will learn and improve in their ability to use new information over time after being fit with a new hearing aid was studied. The study made use of both speech and non speech test that are appropriate to measure the patient's ability to perceive speech. The study also aimed to observe whether DLI can be used to demonstrate the effect. Three subjects participated in the study, all are the hearing aid users for the first time, and are selected after fulfilling certain criteria. They were studied once a month for three months after fitting the hearing aid. Every follow up and at the time of fitting included seeking their performance in pure tone audiometry (pure tone thresholds), SRT, Speech identification scores and DLI (10 dB SL and 40 dB SL), both in aided and unaided conditions. Hearing aid benefit, the difference between the aided and unaided scores, of each test is compared for all the four trials repeated measures ANOVA has been used to find out whether there is any change in the hearing aid benefit. SRT and Pure tone thresholds did not show any change in the benefit. Although the study included only three subjects , the experience of the investigator and the literature evidence, made it clear that such a kind of study is difficult to conduct in Indian scenario. So an optimum follow up model has been recommended.

Follow-up is especially important in case of the children and elderly to change the amplification system to suit the functional changes of the auditory system. These changes are desirable if acclimatization effect takes place, which requires a proper evaluation of the CAS, to check for its plasticity before fitting a hearing aid. It is also required that a suitable hearing aid be given, to demonstrate such an effect.

Theoretically the acclimatization effect should occur, as it is demonstrated with other sensory modalities, such as eyes. Even though its clinical ramifications are small auditory acclimatization effect may bring the auditory functions to normalcy, thus successfully completes the aim of any rehabilitation regime.

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