Aided Speech Recognition Scores and Psychophysical Tuning Curves in Cochlear Pathology Cases

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A Dissertation submitted as part of fulfilment for
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MYSORE

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CERTIFICATE

This is to certify that this dissertation entitled **"Aided Speech Recognition Scores and Psychophysical Tuning Curves in Cochlear Pathology Cases"** is the bonafied work in partial fulfillment for the degree of Master of Science (Speech and Hearing) of the student with register number M.2K22.

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CERTIFICATE

This is to certify that this dissertation entitled **"Aided Speech Recognition Scores and Psychophysical Tuning Curves in Cochlear Pathology Cases"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other university for the award of any diploma or degree.

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DECLARATION

I hereby declare that this dissertation entitled: **"Aided Speech Recognition Scores and Psychophysical Tuning Curves in Cochlear Pathology Cases"** is the result of my own study under the guidance of **Mrs. P. Manjula,** Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

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May, 2002 Reg. No. M.2K22

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INTRODUCTION

Auditory frequency analysis refers to the ability of the auditory system to separate or resolve the components in a complex sound. Auditory frequency analysis may be expressed by two auditory faculties: (1) frequency discrimination, i.e., the ability to discriminate between two successively presented sinusoids, and (2) frequency selectivity or frequency resolution, i.e., the ability to hear one frequency in presence of others (Scharf, 1978). It is generally assumed that these abilities are primarily based on the process which take place peripherally in the auditory system (Evans and Wilson, 1973). The impaired capacity for speech discrimination in patients with a cochlear hearing loss is mainly a consequence of a deteriorated frequency selectivity (Evans, 1975; Scharf, 1978). This hypothesis has not been directly confirmed but is indirectly supported by results which might indicate an impaired frequency selectivity in patients with sensori-neural hearing loss (De Boer, 1959; Hoekstra and Ritsma, 1977).

There are different measures for studying frequency selectivity such as critical band (CB) and psychophysical tuning curves (PTC). Psychophysical tuning curve determines the frequency selectivity. It is a curve showing the level of a narrow band masker needed to mask a fixed sinusoidal signal plotted as a function of masker frequency. The measurement of psychophysical tuning curves (PTCs) involves a procedure that is analogous in many ways to physiological methods for determination of tuning curves on the basilar membrane or a neural tuning curve (Small, 1959).

The shape of the psychophysical tuning curves varies in the normal and pathological ears. In the normal ears, as the hair cells are in a healthy condition, the tuning curves remain sharp at the critical frequency and then broadens as the signal moves to the neighboring frequencies. For the pathological cases, like in the ears with cochlear pathology, the psychophysical tuning curves becomes broader and flatter. A number of studies have revealed that the psychophysical tuning curves are broader than normals in the hearing impaired (Leshowitz, Linstorm and Zurek, 1975; Zwicker and Schorn, 1978; Bonding, 1979; Nelson, 1991). The psychophysical tuning curves change with increasing hearing loss, i.e., rapidly deteriorating beyond normal limit values when the hearing loss exceeded 30 to 40 dB HL (Bonding, 1975). Studies report that there are no systematic differences in the psychophysical tuning curves between cochlear losses of different origin, such as noise induced, Meniere's disease, ageing and hereditary losses (Hoekstra and Ritsma, 1977). It has been suggested that there is a correlation between the sharpness of the psychophysical tuning curves and speech identification ability (Evans, 1975; Bonding, 1979).

NEED:

In the literature, a number of studies report that the speech identification scores correlate with the sharpness of the psychophysical tuning curves (Bonding, 1979; Evans, 1975). However, there have been few reports on the correlation of psychophysical tuning curve (PTC) with aided speech performance.

AIM:

The present study sought to investigate the relationship between the psychophysical tuning curves and the speech recognition scores in patients with cochlear pathology using hearing aids.

REVIEW OF LITERATURE

The functioning of the normal cochlea appears to reflect the operation of the active mechanism that is dependent on the integrity of the outer hair cells (OHCs) within the cochlea. This mechanism may involve the application of forces to the basilar membrane (BM) by the OHCs, and it plays an important role in producing the high sensitivity of the BM to weak sound and the sharp tuning on the BM. The normal BM shows several non-linearities, including compressive input-output functions, two-tone suppression, and combination - tone generation (Robles, Ruggero and Rich, 1986), these non-linearities also appear to depend on the operation of the active mechanism.

Cochlear hearing loss often involves damage to the OHCs and inner hair cells (IHCs), the stereocilia may be distorted or destroyed, or entire hair cells may die. The OHCs are generally more vulnerable to damage than the IHCs (Borg, Canlon and Engstrom, 1995). When OHCs are damaged, the active mechanism tends to be reduced in effectiveness or lost altogether. As a result, several changes occur; the sensitivity to weak sounds is reduced, so the sounds need to be more intense to produce a given magnitude of response on the basilar membrane; also impairing the frequency analysis of the auditory system.

Auditory frequency analysis refers to the ability of the auditory system to separate or resolve the components in a complex sound. Auditory frequency analysis may be expressed by two auditory faculties:

(1) Frequency discrimination, and
(2) Frequency selectivity or frequency resolution (Scharf, 1978)

It is generally assumed that these abilities are primarily based on the process which takes place peripherally in the auditory system (Evans and Wilson, 1973).

The impaired capacity for speech discrimination in patients with a cochlear hearing loss is mainly a consequence of a deteriorated frequency selectivity (Evans, 1975; Scharf, 1978). This hypothesis has not been directly confirmed but is indirectly supported by results which might indicate an impaired frequency selectivity in patients with sensori neural hearing loss (De Boer, 1959; Hoekstra and Ritsma, 1977).

Effects of cochlear damage on frequency Selectivity:

Frequency selectivity refers to the ability of the auditory system to separate or resolve the components in a complex sound. It is often quantified by using masking experiments to measure psychophysical tuning curves (PTCs) or to estimate auditory filter shapes using rippled noise or notched noise. (Glasberg and Moore, 1990). It seems likely that frequency selectivity depends to a large extent on the filtering that takes place in the cochlea (Evans, Pratt and Cooper, 1989). Hence, it would be expected that frequency selectivity, as measured behaviorally, would be poorer than normal in people with cochlear hearing loss.

Comparisons of frequency selectivity in normal hearing and hearing impaired subjects are complicated by several factors. One factor is the sound level of the stimuli used. The auditory filters of subjects with normal hearing sharpen on the low frequency side with decreasing level (Moore and Glasberg, 1987). This effect probably depends on the active mechanism in the cochlea. The active mechanism is usually damaged or completely non-functioning in ears with cochlear damage. Hence, change in frequency selectivity with sound level are absent or much less pronounced (Moore, Laurence and Wright, 1985). As a result, the differences between normal hearing and hearing impaired subjects tend to decrease at high sound level.

A second complicating factor is off-frequency listening, the signal may be detected using an auditory filter that is not centered at the signal frequency (Davies and Patterson, 1979). Some measures of frequency selectivity, especially PTCs, can be strongly influenced by off-frequency listening. More importantly the role of off-frequency listening may vary markedly depending on the sensation level (SL) of the stimuli and the frequency selectivity of the subject.

O' Loughlin and Moore (1981) reported methods for improving psychoacoustical tuning curves. According to them, the probe signal in psychoacoustical tuning curves stimulates more than one neuron, even when presented at low levels. The subject can 'listen' to neurous with characteristic frequencies away from the nominal probe frequency and optimize performance. This off-frequency listening can account for much of the discrepancy in the sharpness of tuning between psychoacoustical tuning curves obtained in forward masking and neurophysiological tuning curves. The addition of a band-reject noise, centered on the probe frequency, to limit off-frequency listening, results in close agreement with the neurophysiological data. In the measurement of PTCs, the masker and probe stimulus may be presented simultaneously. However, lateral suppression, combination tones and 'beats' between the masker and probe confound the results. Forward masking where a brief probe is preceeded by the masker, is often preferred, but there remains the problem that the probe, even at a low level, stimulates a numbers of neurons; and thus the 'summed' frequency selectivity is determined.

Many of the difficulties associated with forward masking PTCs, which decrease their comparability with neuro physiological tuning curves, are conceptually reducible to the use of information from an array of neurous. The addition of the band reject noise, centered on the probe frequency, should theoretically reduce the importance of neurous with characteristic frequencies farther from the probe's nominal frequency region. The simultaneous presentation of the stationary and variable maskers will produce suppression effects which vary as the frequency of the variable masker changes. The symmetry of the band-reject noise around the probe frequency would be expected to have a distorting influence on the PTC, if, as the evidence suggests, the underlying patterns of excitation of the probe and the maskers within the auditory system are asymmetric. Nonetheless, the method used, appears most suitable so far for the determination of forward masking PTCs.

Moore, Glasberg and Roberts (1984), conducted experiments in an attempt to refine the measurement of psychophysical tuning curves (PTCs). They determined psychophysical tuning curves (PTCs)

(1) Using a fixed low-level notched noise,
(2) With and without an additional notched - noise masker
(3) Using simultaneous masking,
(4) To study the effect of signal delay in forward masking.

It was concluded that, when PTCs were determined in the presence of notched noise, suppression was probably responsible for most of the differences between simultaneous and forward masking. The use of a fixed notched noise in the determination of PTCs was recommended as a method of minimizing the influence of factors which might confound the PTC as an estimate of frequency selectivity.

Davies and Patterson (1979) reported the frequency selectivity using the psychophysical tuning curves. They generated PTCs for three listeners by determining threshold for a 2.0 kHz sinusoid fixed at 20 dB SPL as a function of the level and frequency of a narrow band noise masker. Then the listening band available to the listeners was restricted by inserting a low level stationary masker at 1.8 kHz. The stationary masker alone did not mask the signal but it depressed the upper branch of the tuning curve by as much as 20 dB. The lower branch of the curve was essentially uneffected. When the low level stationary masker was repositioned to 2.2 kHz the effect was reversed, the lower branch of the tuning curve was depressed but the upper branch was slightly changed. The combined results showed that the thresholds on the two branches of the tuning curve are based on information in different frequency regions and indicate that even at reasonably low signal levels the traditional PTC overestimated the frequency selectivity of the ear.

Nelson and Fortune (1991) reported at the recording of high level psychophysical tuning curves using simultaneous masking by pure tones and 100 Hz wide noise bands. The results revealed that, tuning in the normal auditory system broadened notably with stimulus level, once off-frequency listening cues, such as combination tones or combination bands, were eliminated. The low level simultaneously masked tuning curve demonstrated a sharp band pass tuning characteristic, whereas, the high level simultaneously masked tuning curve in background noise demonstrated a broad low-pass tuning characteristic. It was argued that comparisons of tuning in impaired ears with tuning in normal ears should be made using estimates of tuning in normal ear that are not influenced by combination tone or combination band detection cues.

Effects of cochlear damage on speech perception:

One of the most common complaints of people with cochlear hearing loss is difficulty in understanding speech. There has been considerable controversy in the literature about the reasons for this difficulty. Some researchers suggest that the difficulty arises primarily from reduced audibility, i.e., for a given speech level, the proportion of the speech spectrum which is above threshold is less than that in normal listeners (Humes, Dirks and Kincaid, 1987). Other researchers (Dreschler and Plomp, 1980, Plomp, 1978) argue that the difficulty arises, at least partly, from changes in the perception of sounds which are well above the absolute threshold. However, for greater losses, poor discrimination of suprathreshold (audible) stimuli is also of major importance.

Hearing impaired people with mild to moderate cochlear hearing loss do not generally have difficulty in understanding connected discourse in a quiet, non-reverberant room. However, they may have some difficulty for isolated nonsense syllables. Subjects with severe losses can have considerable difficulty with speech in quiet.

Turner and Robb (1987) tried to determine whether this difficulty could be explained in terms of audibility. They studied the identification of synthetic consonant vowel. Syllables composed of one of the six stop consonants / b, g, d, p, t, k / followed by vowel |a|. A model of filtering in the peripheral auditory system was used to estimate the portion of the speech spectrum that was above the threshold of audibility for a given presentation level. Several presentation levels were used for each subject. They tested four normally hearing subjects and five subjects with moderate to severe hearing losses. The results strongly suggested that reduced audibility is not sufficient to explain the relatively poor consonant recognition of the hearing impaired subjects. Even presentation levels of 100 dB SPL were not sufficient to provide 100% audibility for subjects with severe losses. Further, the results suggested that one or more factors other than audibility contribute to the difficulties of speech perception experienced by those with moderate or greater cochlear losses. This is especially true in situations where the stimuli are presented at high levels and / or in background noise. In other words, the difficulties arise partly from abnormalities in perception of sounds that are above the threshold of audibility. For those with mild losses, audibility may be the dominant factor.

Killion and Fikret-Pasa, 1993, have also discussed this aspect and have explained the effect of hearing loss based on classification of hearing loss into three types; Type 1, Type 2, Type 3. In Type 1 loss the sounds below 40 dB HL are inaudible. This finding is consistent with a loss of outer hair cell functions with normal inner hair cell function. With increasing level above 40 dB HL, loudness gradually returns to normal Not only has loudness returned to normal for high - level sounds, but you can find subjects with 40 dB threshold loss who appear to have normal or near normal high - level hearing.

In Type 2 hearing loss the sounds below 60 dB HL are inaudible. Here/there is a loss of outer hair cell function along with some inner hair cell loss as well. With a Type 2 loss, there is not only a loss of sensitivity for quiet sounds, but also a loss of some speech cues. A loss of inner hair cells means there is less information available to be transmitted to the brain, even for intense sounds. There will usually be a deficit in intelligibility for speech, especially in noise.

In Type 3 loss the sounds below 75 dB are inaudible. Here,there is more loss of inner hair cells. This affects the speech intelligibility both in noise and in usual conditions.

Sommers and Humes (1993) reported the auditory filter shapes in normal hearing, noise masked normals and elderly listeners. To dissociate the effects of age and hearing impairment on changes in frequency selectivity, auditory filter shapes were measured at 2 kHz in four groups of subjects;

(1) Normal hearing young subjects
(2) Normal hearing elderly subjects
(3) Elderly hearing impaired listeners and
(4) Young normal hearing listeners with simulated hearing losses.

The finding suggested that the reduced frequency selectivity often reported for older listeners could be attributed, primarily, to hearing loss rather than increased age.

Florentine, Buus, Scharf and Zwicker (1980) compared frequency selectivity, in observers with normal hearing and in observers with conductive, otosclerotic, noise-induced or degenerative hearing losses. Each category of loss was represented by center frequencies of 500 Hz and 4000 Hz. Four measurements were made: which included psychophysical tuning curves, narrow-band masking, two tone masking and loudness summation. Results showed that:

a) Frequency selectivity were reduced at frequencies where a cochlear hearing loss was present,

b) Frequency selectivity was reduced regardless of the test level at which normally - hearing observers and observers with cochlear impairment were compared,

c) All four measures of frequency selectivity were significantly correlated and

d) Reduced frequency selectivity was positively correlated with the amount of cochlear hearing loss.

In the above mentioned study the frequency selectivity was determined based on the sharpness of the tuning curve which was calculated using the Q_{10} values. The Q_{10} values were measured by, the center frequency divided by the bandwidth at a level 10 dB below the level of the masker. The results indicated that the Q_{10} values were significantly reduced for the otosclerotic ears, the noise induced and degenerative groups.

Stelmachowicz, Jesteadt, - Gorgo. and Mott (1985) found that the psychophysical tuning curves of hearing impaired correlated with their speech perception ability. This was established for individuals with cochlear pathology with flat, moderate sensorineural hearing losses.

Preminger and Wiley (1985) studied the relations between frequency selectivity and consonant intelligibility in subjects with sensorineural hearing loss in an attempt to derive predictive indices. Three matched pairs of subjects with similar audiometric configurations (high frequency, flat or low frequency hearing loss) but significantly different word - intelligibility scores were tested. Characteristics of psychophysical tuning curves (PTCs) for high- and low- frequency probes were compared with speech intelligibility performance for high- and low-frequency consonant vowel syllables. Frequency-specific relations between PTC characteristics and consonant intelligibility performance were observed in the subject pair with high frequency and flat sensorineural hearing loss. Corresponding results for the subject pair with low frequency sensorineural hearing loss were equivocal.

Dubno and Schaefer (1992) reported comparison of frequency selectivity and consonant recognition among hearing impaired and masked normal hearing listeners. Frequency selectivity and consonant recognition were determined for normal hearing and hearing impaired listeners using techniques that facilitate comparisons of performance among listeners whose absolute thresholds vary in magnitude and configuration. The results suggested that frequency selectivity is poorer for hearing impaired listeners than for masked normal hearing listeners, even when thresholds among subjects were equated, but the deviation from normal frequency selectivity is smaller than, that estimated from comparisons with normal-hearing listeners, in quiet. Although frequency selectivity is reduced, there is no consistent difference in consonant recognition between hearing-impaired subject and masked normal-hearing subjects, when performance is accessed under conditions that assure equal speech-spectrum audibility across subjects.

Bonding (1979) reported frequency selectivity and speech discrimination in sensorineural hearing loss subjects. He studied two measures of auditory frequency selectivity -critical band (CB) in loudness summation and psycho acoustic tuning curve (PTC), both measured at 1 kHz were compared with the capacity for speech discrimination in patients with various cochlear disorders and a relatively flat pattern. The CB in loudness summation was correlated neither to the degree of hearing loss nor to the speech discrimination score. In contract, the PTC changed with increasing hearing loss in the same manner as the electrophysiological tuning curve (FTC), i.e., rapidly deteriorating beyond normal limit values, when the hearing loss exceeded 30 - 40 dB (HL). Nearly the same dependency of the degree of the hearing loss was demonstrated for the speech discrimination score and a significant correlation was present between this score and cochlear tuning, as expressed by the PTC. It is proposed that the PTC is a more valid measure of auditory frequency selectivity than the CB in loudness summation. This result seems to support the hypothesis of impaired frequency selectivity as a major cause for deteriorated speech discrimination in patient, with cochlear disorder.

Glasberg and Moore (1986) estimated the shape of the auditory filter at three center frequencies, 500 Hz, 1 kHz and 2 kHz for five subjects with unilateral cochlear impairment. Additional measurements were made at 1 kHz using one subject with a unilateral impairment and six subjects with bilateral impairment. Subjects chosen had a relatively flat thresholds as the function of frequency and ranged from 15 to 70 dB HL. They concluded that for normal ears, the filters were markedly asymmetric for centre frequencies of 1 kHz and 2 kHz, the high frequency branch being steeper. At 500 Hz the filters were more symmetrical. For the impaired ears, the filter shapes varied considerably from one subject to another. For most subjects, the lower branch of the filter was much less steep than normal. The upper branch was often less steep than normal, but a few subjects showed a near normal upper branch.

Zurek and Formby (1979) reported that the ability of the hearing impaired listener, relative to normal hearing listener to detect a sinusoidal frequency modulation; was diminished above a certain level of hearing loss; and was more disrupted for low frequency tones, than for high frequency tones, given the same degree of hearing loss at the test frequency. Overall it has been reported that the frequency discrimination ability was poor in hearing impaired listeners.

Moore and Glasberg (1986) described two experiments in which frequency selectivity was estimated, in simultaneous and forward masking for each ear of subjects with moderate unilateral cochlear hearing losses. He concluded that for the normal ears, the PTCs were sharper in forward masking than in simultaneous masking. For the impaired ears the PTCs were similar in simultaneous and forward masking, but those in forward masking tended to be shaper at masker frequencies far removed from the signal frequency. Overall, the results suggested that suppression was reduced, but not completely absent in cases of moderate cochlear hearing loss.

Nelson (1991) obtained forward masked PTCs for 1000 Hz probe tones at multiple probe levels from one ear of 26 normal hearing listeners and from 24 ears of twenty one hearing impaired listeners with cochlear hearing loss. Comparisons between psychophysical tuning curves of normal hearing and hearing impaired individuals were made at equivalent masker levels near the tip of PTCs. He concluded that:

1) Normal tuning changes with increasing masker level from sharp band pass characteristic at low levels to a broad low pass characteristic at high levels. This change in tuning is evidenced on the low frequency sides of forward masked PTCs from both normal-hearing and hearing impaired ears. Tail slopes and LF slopes became more shallow as masker levels near the tips of the PTCs increased. The most appreciable changes were seen with tip levels above 55 dB SPL.

2) Abnormal frequency resolution was seen only on the high frequency (HF) sides of forward masked PTCs. It was conduced by HF segments with slopes less than 100 dB/octave. Abnormal frequency resolution appeared as abnormal downward spread of masking.

3) Abnormal frequency resolution was seen only in hearing impaired ears when hearing loss at the probe frequency exceeded 40 dB. However, not

all ears with more than 40 dB hearing loss at the probe frequency demonstrated abnormal frequency resolution.

4) Significant hearing loss above the probe frequency did not lead to obvious deficits in frequency resolution at the probe frequency.

It would appear that some, but not all, cochlear hearing losses greater than 40 dBHL influence the sharp tuning capabilities usually associated with outer hair cell function.

Horst (1987) reported the frequency discrimination of spectral envelopes of complex stimuli, frequency selectivity measured with PTCs, and speech perception that were determined in hearing impaired subject each having a relatively flat, sensory-neural loss. Both the frequency discrimination and speech perception measures were obtained in quiet and in noise. Most of these subjects showed abnormal susceptibility to ambient noise with regard to speech perception. Frequency discrimination in quiet and frequency selectivity did not correlate significantly. At low signal-to-noise ratios, frequency discrimination correlated significantly with frequency selectivity. Speech perception in noise correlated significantly with frequency selectivity and with frequency discrimination at low signal to noise ratios.

Hearing aid appropriateness and psychophysical tuning curves:

The appropriateness and effectiveness of the hearing aid fitting continues to be the most challenging areas in the process of aural rehabilitation. The principle aim of any hearing aid selection and fitting strategy is to ensure that environmental sounds, especially conversational speech, is audible without being excessively loud. To achieve a successful fitting, a hearing aid must provide appropriate amplification to maximize speech recognition, provide good sound quality and provide amplification that is comfortable. To accomplish this, the frequency - gain response of the hearing aid must be shaped to compensate for the loss of loudness as a result of impaired hearing (McCandless, 1994).

A more recent approach in hearing aid fitting has been the calculation of desired electroacoustic characteristic based on the results of various psychoacoustic data such as pure-tone threshold, most comfortable levels (MCL), uncomfortable levels (UCL), and bisecting the dynamic range. Prescriptive procedures make general assumption that, if average conversation speech is amplified to the listeners comfortable loudness level, the fitting will result in user satisfaction by providing acceptable sound quality, clarity of speech and comfort. The prescriptive procedures are based on audiometric data, it is assumed that, even without actually testing these functions, restoration of acuity, equal loudness, or speech spectrum to the ear can be correctly inferred from audiometric data.

Threshold based prescriptive rules:

Since a linear hearing aid provides the same amount of amplification for soft as well as loud sounds, the problem in providing adequate gain in the pathological ear with recruitment is to arrive at a reasonable compromise. Most hearing aid users, have varying amount of loudness recruitment, so the volume control of hearing aid is adjusted to amplify soft sounds to a comfortable listening level but frequently makes louder sounds uncomfortable. When a hearing aid is adjusted to a comfortable level for loud sounds, the softer sounds, including those of speech, are often inaudible.

A logical choice of gain is to prescribe a level that permits hearing sounds that are most important without being excessively loud, that is, near the MCL level. Although an individual's choice of preferred listening level for amplified sound depends on many factors, on the average, preferred listening levels amount to about one-half of the average hearing threshold.

At least half of the prescriptive procedures are based on audiometric pure-tone thresholds. Since each prescriptive procedure has its own rationale and since the various formulae yield significantly different prescribed gain requirements, not all can be expected to yield equivalent maximum speech recognition, improved sound quality, or maximum satisfactory results. Procedures also differ in their efficiency, ease of computation and general clinical utility. Of the many prescriptive procedures proposed over years, only a few are in general use. The four generally used procedures are (1) Berger (1984), (2) Libby one-third Gain (Libby, 1986), (3) NAL - Revised (Byrne and Dillon, 1986) and (4) Prescription of Gain and Output (McCandless, 1983).

There is no consensus as to whether various prescriptive technique result in significant differences in speech recognition, sound quality or clarity. One point of view states that minor difference in frequency gain responses between prescriptive formulae would likely be minimal, especially when adjustment of the volume control is considered.

Prescribing and Verifying Frequency - Gain characteristics: Functional and Insertion Gain.

Essential to the success in implementing prescriptive fitting is the knowledge of the concepts of functional and insertion gain. Functional gain is a psychoacoustic or behavioural measure and usually refers to the difference in decibels between aided and unaided sound field warble tone and / or spondee threshold.

Insertion gain is an electro acoustic, rather than a psychoacoustic, term and is the difference in decibels between the sound pressure level measured at or near the ear drum with and without a hearing aid in place in the ear canal. As with functional gain measures, insertion gain is measured with the volume control adjusted to a comfortable listening level.

Functional or insertion gain measures are used in two important ways in the context of prescriptive hearing aid evaluation and fitting. The first is the calculation of the prescribed gain based on threshold data. The second application is when frequency gain response is measured while wearing the hearing aid.

Measured functional and insertion gain, values may be similar but not identical, since functional gain measures are determined from behavioural sound field thresholds and insertion gain measures are a physical measure obtained in the ear canal. However, on the average, functional and insertion gains are sufficiently close as to be clinically valid.

A hearing aid, when selected using the prescriptive method either measuring the functional gain or insertion gain - would optimize the speech understanding. The psychophysical tuning curves may be utilized for predicting the performance with hearing aid.

METHOD

This study was aimed at investigating the relationship between the psychophysical tuning curve and the speech recognition scores in patients with cochlear pathology using hearing aids.

Subjects:

The subjects were divided into two groups, i.e., ***Group 1,*** the experimental group and ***Group 2,*** the control group. Group 1 included ten ears of ten subjects with acquired sensorineural hearing loss, ranging from moderate to moderately severe (41 dB HL to 70 dB HL) in degree and the audiometric slope of not more than 12 dB rise or fall per octave slope. The duration of hearing impairment was not more than two years and the subjects were naive hearing aid users. The age of the subjects ranged from 18 years to 55 years, irrespective of the gender. All the subjects in the study were fluent in Kannada. Group 2, the control group, consisted of 30 ears of subjects with otoscopically normal ears with pure tone threshold of less than or equal to 20 dB HL at all audiometric frequencies.

Test Environment:

The testing was done in air-conditioned sound treated double suite, with the noise levels within permissible limits (ANSI, 1991).

Equipment and Material:

- A calibrated dual channel diagnostic audiometer, Maico MA 53, with TDH - 39 earphones enclosed in MX 41/AR ear cushion, Radio ear B - 71 bone vibrator and free field loud speakers Maico SBC.
- A calibrated middle ear analyzer, GSI- 33 (version 2).

- Insertion gain optimizer of Fonix 6500 C.
- Behind- The- Ear Hearing Aids.
- Speech material - List of monosyllables (Maya Devi, 1974) for establishing Speech Recognition Scores (SRS).

  List of paired words (Rajashekhar, 1976) for establishing Speech Reception Thresholds (SRT).

Test Procedure:

1. A pure tone audiogram was initially obtained using the Modified Hughson-Westlake procedure (Carhart and Jerger, 1959). For ruling out retro-cochlear pathology, supra threshold adaptation test (STAT) was administered.

2. Speech audiometry, through headphones, was carried out, comprising of the speech reception threshold (SRT), speech recognition scores (SRS) and uncomfortable level for speech (UCL). The speech recognition scores were not converted into percentage scores, instead raw scores were used.

3. Immittance evaluation, comprising of tympanometry and reflex testing (ART) was done to rule out the conductive pathology.

4. Psychophysical tuning curves at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were obtained for all the subjects, using the audiometer. For the *control group* psychophysical tuning curves were obtained for right and left ears and for the *experimental group* psychophysical tuning curves were obtained for the ear which was selected for amplification. For plotting the psychophysical tuning curves following steps were followed:
   a) A pure tone (pulsed) was presented at each of the 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz frequencies at 10 dB sensation level.
   b) Each tone was masked using seven narrow bands with the bandwidth of the masker being 100 Hz. The narrow band noise concentrated in

three bandwidths below and four bandwidths above the test frequency.

c) The intensity of the narrow band noise was changed in 5 dB steps during simultaneous masking of the pulsed pure tone.

d) The subjects were required to respond for the signal till pulsed pure tone was just inaudible in the presence of narrow band noise. The obtained intensity level of the narrow band noise was plotted on the graph sheet.

e) For each test frequency, seven narrow band maskers were used, three below and four above the test frequency. This was plotted as illustrated in the Figure 1.

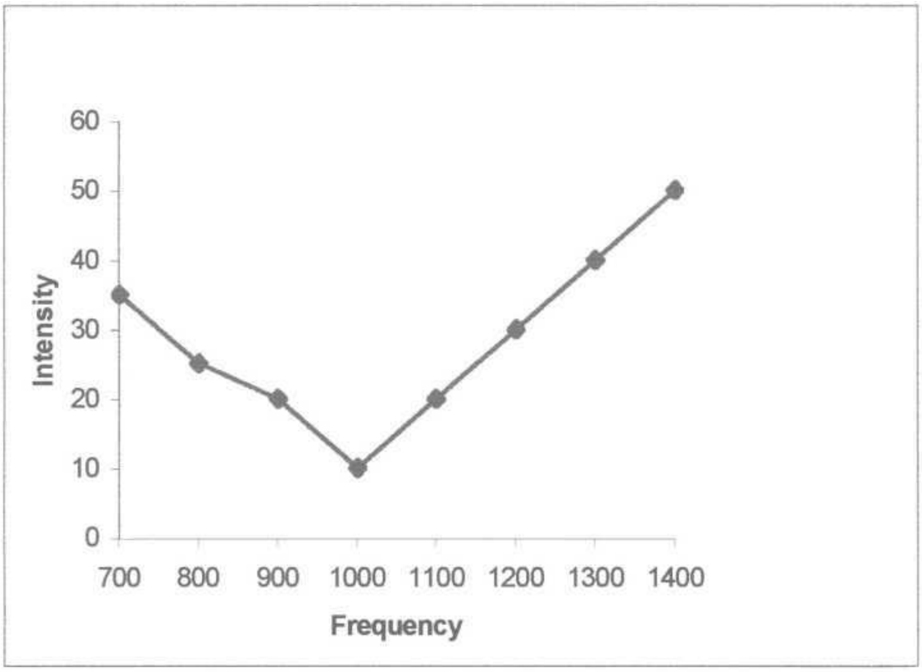

Figure 1. Psychophysical timing curves at 1000 Hz.

5. After obtaining the psychophysical tuning curves, to determine the sharpness of the curve, Q_{10} value was established for each tuning curve by using the equation.

$$Q_{10} = \text{Center frequency / Bandwidth}$$

For calculating the bandwidth, a level of 10 dB above the peak (A-center frequency) was taken and the difference between the two frequencies (B and C) corresponding to the points, where the psychophysical tuning curve was intersected, was considered as the bandwidth. More the value of Q 10, sharper was the psychophysical tuning curve. Figure 2. illustrates the center frequency and bandwidth for calculation of Q_{10}.

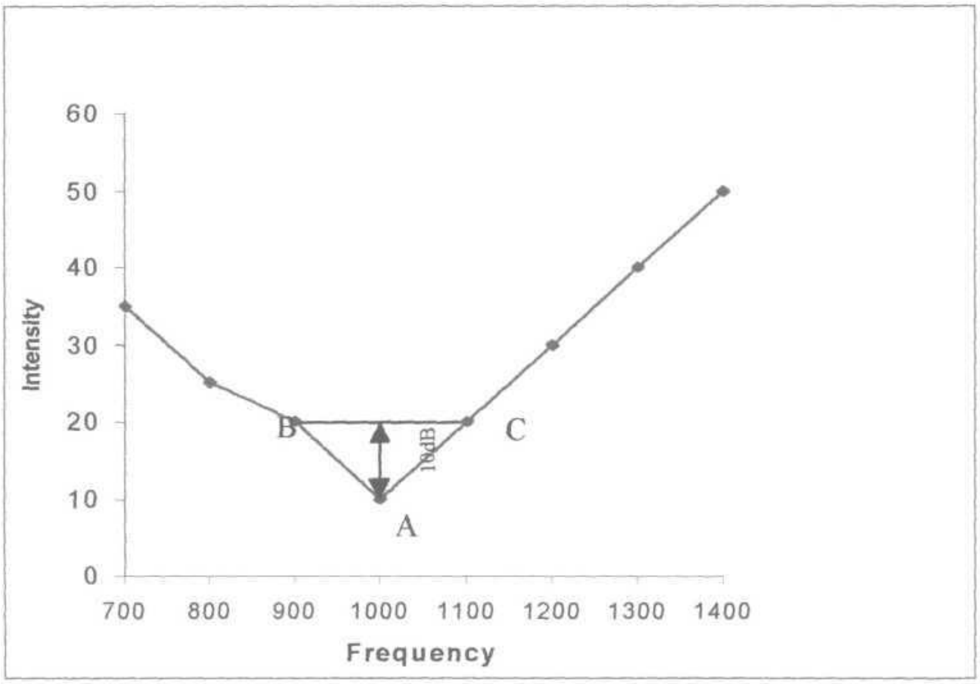

Figure 2. Illustration for calculation of Q_{10}

All these steps were administered for all the subjects. The following step was administered only for the hearing impaired subjects.

6. Hearing aid selection was done using Insertion gain measurement (IGM). The ear which satisfied the hearing aid fitting criteria was fitted with the preselected hearing aid. The protocol used was as follows:
   a) Leveling of the instrument was done on the *probe* selection menu.
   b) The audiometric thresholds of the subject were fed to the system by using *create target* option.

c) The prescriptive formula selected for the fitting was Prescription of gain output (POGO) and the target gain curve was obtained.

d) After obtaining the target gain, Real Ear Unaided Response (REUR) was obtained by inserting the probe tube in the ear canal. The length of insertion of the probe tube was kept 5 mm longer than length of the canal of the earmold.

e) An appropriate hearing aid was then put on to the subject's ear and the Real Ear Aided Response (REAR) was obtained.

f) From the above two curves i.e., REUR and REAR, Real Ear Insertion Response (REIR) was obtained which was then matched with the target gain curve by changing the settings of the hearing aid or by changing the hearing aid.

7. After selecting the best suitable hearing aid for the subject, an aided speech recognition score (SRS) was obtained at 40 dB HL, in the sound field, for checking the performance with amplification.

Analysis:

Statistical analysis was done:

1. To compare the sharpness of the tuning curves of the experimental group with that of the control group.
2. To compare the sharpness of the tuning curves of the control group with their speech recognition scores (SRS).
3. To compare the sharpness of the tuning curves of the experimental group with the unaided speech recognition scores (UA-SRS).
4. To compare the sharpness of the tuning curves of the experimental group with the aided speech recognition scores (A-SRS).
5. To compare the speech recognition scores (SRS) of control group and unaided speech recognition scores (UA-SRS) of the experimental group.
6. To compare the aided speech recognition scores (A-SRS) and unaided speech recognition scores (UA-SRS) of the experimental group.

RESULTS AND DISCUSSION

The aim of the present study was to investigate the relationship between the psychophysical tuning curves and the speech recognition scores in cases with cochlear pathology using hearing aids. Psychophysical tuning curves were obtained at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz for the experimental group (cochlear pathology) and the control group (normals). The speech recognition scores were also obtained in aided and unaided condition for the experimental group and in unaided condition for the control group. The data collected from the two groups, control group and experimental group, were statistically analysed.

Independent Sample T-test was done in order to :

a. Compare the sharpness of the tuning curves of the experimental group with that of the control group.
b. Compare the speech recognition scores (SRS) of the control group with the unaided speech recognition scores (UA - SRS) of the experimental group.
c. Compare the speech recognition scores (SRS) of the control group with the aided speech recognition scores (A-SRS) of the experimental group.
d. Compare the aided speech recognition scores (A-SRS) with the unaided speech recognition scores (UA-SRS) of the experimental group.

Paired sample correlations were done to:

e. Compare the sharpness of the psychophysical tuning curves and speech recognition scores (SRS) of the control group.
f. Compare the sharpness of the psychophysical tuning curves and unaided speech recognition scores (UA-SRS) of the experimental group.
g. Compare the sharpness of the psychophysical tuning curves and aided speech recognition scores (A-SRS) of the experimental group.

For quantifying the psychophysical tuning curves, Q_{10} values were calculated for each of the PTCs at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, in both the experimental group and the control group. Greater is the value of Q_{10}, sharper is the psychophysical tuning curve and better is the frequency selectivity.

a. Q_{10} values of the psychophysical tuning curves in control group and experimental group:

	Q_{10} at 500 Hz		Q_{10} **at 1000 Hz**		Q_{10} **at 2000 Hz**		Q_{10} **4000 Hz**	
	EG	**CG**	**EG**	**CG**	**EG**	**CG**	**EG**	**CG**
Mean	1.02	2.70	1.76	4.16	3.06	8.40	5.51	11.43
SD	0.18	0.68	0.48	0.74	0.44	2.01	0.46	5.62
2- tailed T-test	.000		.000		.000		.036	

Table 1: The Mean, SD and T-test values of Q_{10} of the PTCs of experimental group (EG) and control group (CG).

The result indicated that there was a significant difference (<0.05) between the Q_{10} of the PTCs obtained for the control group and the experimental group at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

In the present study, the sharpness of psychophysical tuning curves were measured using the Q_{10} values. The Q_{10} values obtained revealed that the PTCs for the experimental group were flatter and broader and for the control group the PTCs were sharper. The occurrence of broad and flat PTC could be due to impaired frequency selectivity of the cochlea. Psychophysical tuning curves obtained for experimental group and control group are shown in Figure 3a and 3b.

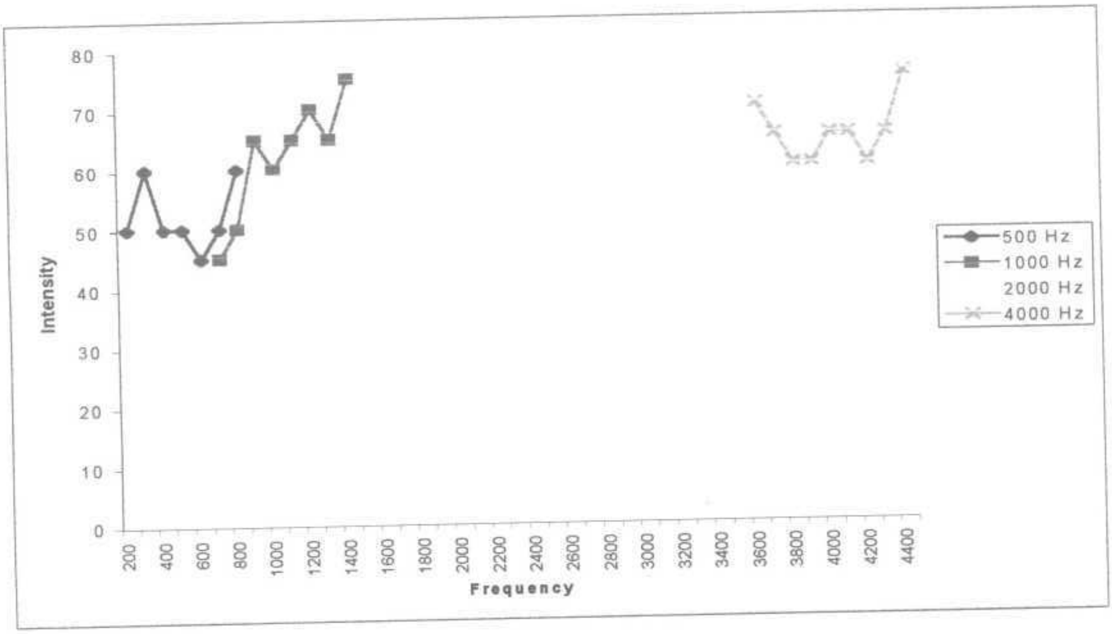

Figure 3a.: *PTCs of the experimental group*

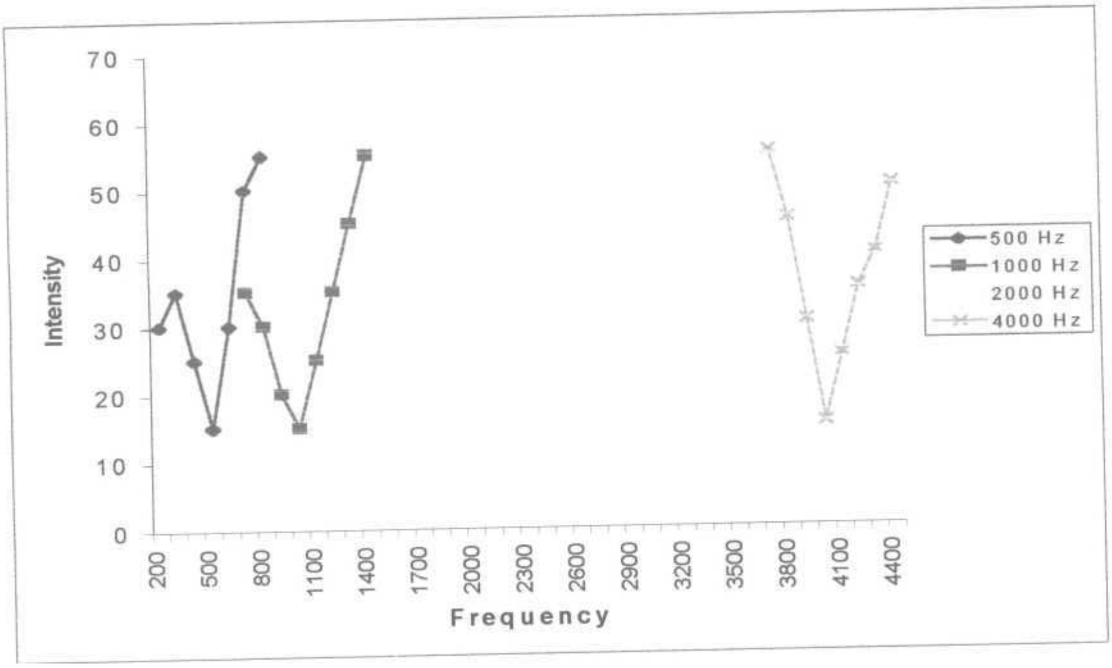

Figure 3b: *PTCs of the control group*

Further, this finding conforms to that found in literature. Shape of the psychophysical tuning curves varied in the normal and the pathological ears. In the normal ears, as the hair cells are in healthy condition, the tuning curve remained sharp at the critical frequency and then broadened as the signal moved to the neighbouring frequencies. For the pathological ears, PTCs were broader and flatter (Leshowitz, Linstrom and Zurek, 1975, Zwicker and Schorn, 1978, Bonding, 1979; Nelson, 1991). Florentine (1980) compared frequency selectivity in observers with normal hearing and in observers with conductive, otosclerotic, noise - induced or degenerative hearing losses. He concluded that (a) frequency selectivity were reduced where a cochlear hearing loss was present; (b) reduced frequency selectivity was positively correlated with the amount of cochlear hearing loss.

In the present study, it was observed that the high frequency branch was steeper than the low frequency branch at 1 kHz and 2 kHz centre frequencies for the control group. As for the experimental group the shapes of the PTCs were varied from one subject to another. This observation was supported by Glasberg and Moore (1986) who reported that for the normal ears, the auditory filters were markedly asymmetric for centre frequencies of 1 kHz and 2 kHz, the high frequency branch being steeper. At 500 Hz the filters were more symmetrical. For the impaired ears, the filter shapes varied considerably from one subject to another. The lower branch of the filter was much less steeper than normal.

b. Speech recognition scores (SRS) for the control group and the unaided speech recognition scores (UA-SRS) for the experimental group:

	Mean	**SD**	**2-tailed T-test**
CG-SRS	20.00	.00	**.000**
EG UA-SRS	14.87	1.88	

Table 2: Mean, SD and T-test values of SRS for control (CG) group and unaided SRS (UA-SRS) for experimental (EG) group.

Speech recognition scores (SRS) were obtained using monosyllabic word list (Maya Devi, 1974), for the experimental and the control group. The SRS obtained here were in unaided condition for both the groups under the headphones, 40 dB SL above the speech reception threshold (SRT). Twenty monosyllables were presented, and the correct responses were retained as it is and were not converted into percent scores.

The results indicated that there was a significant difference (<0.01) between the SRS for control group and unaided SRS, for the experimental group. In the present study, the cochlear pathology cases showed poor SRS scores. This can be attributed to the difficulty arising primarily from reduced audibility, i.e., for a given speech level, the proportion of the speech spectrum which is above threshold is less than in normal listeners (Humes, Dirks and Kincaid, 1987). Turner and Robb (1987) reported that reduced audibility is not sufficient to explain the relatively poor consonant recognition of the hearing impaired. They suggested that one or more factors other than audibility contribute to the difficulties of speech perception experienced by those with moderate or greater cochlear losses. This is specially true in situations where the stimuli are presented at high levels and/or in background noise. In other words, the difficulties arise partly from abnormalities in perception of sounds that are above the threshold of audibility.

c. Speech recognition scores for the control group and aided speech recognition scores (A-SRS) for the experimental group:

	Mean	**SD**	**2-tailed T-test**
CGSRS	20.00	0.00	.000
EG A-SRS	15.37	1.30	

Table 3: Mean, SD and T-test values of SRS for control (CG) group and aided SRS (A-SRS) for experimental group (EG).

Aided speech recognition scores were obtained at 40 dB HL, in the sound field. The hearing aid which was best suited to the case was used in order to obtain the scores. The control group subjects were also given the same level of sound to obtain the scores.

The results revealed that there was a significant difference (<0.01) between the speech recognition scores (SRS) for the control group and speech recognition scores (A-SRS) for the experimental group, even in aided condition. All the subjects in the control group had a score of 20 (out of 20). The results obtained here indicate that the speech recognition scores on amplification remain significantly poorer in the impaired ear when compared to the normals, and slightly improved compared to that in unaided condition. This may be because of the broader and flatter PTCs or reduced frequency selectivity and not just reduced audibility.

Further, it has been reported by Turner and Robb (1987), and Killion and Fikret - Pasa (1993) that for mild losses, audibility may be the dominant factor. But with moderate or greater cochlear losses there are various factors other than audibility that contribute? to the difficulties in speech perception.

d. Aided speech recognition scores (A-SRS) and unaided speech recognition scores (UA-SRS) for the experimental group:

	Mean	SD	2-tailed T-test
EG UA-SRS	14.87	1.88	0.547
EG A-SRS	15.37	1.30	

Table 4: Mean, SD and T-test values of A-SRS and UA-SRS for experimental group (EG).

Aided and unaided speech recognition scores were obtained for the experimental group. The result revealed that there was no significant difference between the aided and unaided speech recognition scores for the experimental group.

Thus it may be inferred that providing amplification to the impaired ear does not bring any significant difference in the scores of speech recognition, i.e., the speech recognition ability remains poor even after providing the best suitable amplification to the subject. Or in other words, it can also be inferred that, on amplification, the audibility to the sound may improve but the speech scores remain unchanged.

e. Psychophysical tuning curves (PTCs) and speech recognition scores (SRS) for the control group:

Pair samples of CG	Correlation	Significance
Q_{10} 500 Hz and SRS	0.056	0.770
Q_{10} 1000 Hz and SRS	0.218	0.248
Q_{10} 2000 Hz and SRS	0.075	0.694
Q_{10} 4000 Hz and SRS	0.018	0.957

Table 5: The paired sample correlation of the Q_{10} of PTCs and SRS for control group (CG).

The psychophysical tuning curves (PTCs) at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz for the control group were correlated to the speech recognition scores (SRS). The results indicated that there was a positive correlation between PTCs and the SRS, and the correlation was highest at 1000 Hz followed by 2000 Hz, 500 Hz and 4000 Hz. The correlation obtained was not significant. The correlation being non-significant may be attributed to the less number of subjects in the control group.

Stelmachowicz, Jesteadt, Gorga and Mott (1985) reported that the speech perception ability of the normal hearing subjects correlates with the psychophysical tuning curves at 1000 Hz and 2000 Hz. In the present study, it was seen that the speech recognition scores were 20 (out of 20) for the control group and the Q_{10} values of the psychophysical tuning curves were also higher. The psychophysical tuning curves appeared sharp and narrow for the control group indicating good frequency selectivity which can be attributed for the good speech recognition scores.

f. Psychophysical tuning curves (PTCs) and unaided speech recognition scores (UA-SRS) for the experimental group:

Pair samples of EG	Correlation	Significance
Q_{10} 500 Hz and UA-SRS	0.364	0.376
Q_{10} 1000 Hz and UA-SRS	0.236	0.610
Q_{10} 2000 Hz and UA-SRS	0.349	0.397
Q_{10} 4000 Hz and UA-SRS	-0.333	0.584

Table 6: Paired samples correlation of Q_{10} of the PTCs and UA-SRS for experimental group (EG).

The results indicated a positive correlation of the PTCs at 500 Hz, 1000 Hz, 2000 Hz, and a negative correlation of the PTC at 4000 Hz with the unaided speech recognition scores (UA-SRS) for the experimental group. The correlation obtained was not significant, this may be due to the limited number of subjects in the experimental group.

The PTCs obtained for the experimental group were broader and flatter with low Q_{10} values and the speech recognition scores were also low compared to the control group. This can be related to each other, i.e., broader and flatter PTCs represent a poor frequency selectivity and a poor frequency specific cochlea, will have a speech recognition problem. In case of cochlear pathology, off-frequency listening takes place, this causes the PTCs to be broader covering a more frequency range and thus less frequency specific. And this, on the other hand, reflects on the speech recognition scores.

In the present study there was positive correlation between PTCs at 500 Hz, 1000 Hz, 2000 Hz and the unaided SRS. Only at 4000 Hz there was a negative correlation with unaided SRS. This may be attributed to the high sensitivity of the basal end of the cochlea, as the basal end of the cochlea is more prone to damage. The basal end due to its anatomical positioning/and constraints is likely to be affected first, giving rise to a difficulty in perception of high frequency syllables.

Stelmachowicz, Jesteadt, Gorga and Mott (1985) found that the PTCs of hearing impaired correlated with the speech perception ability. This was established for individuals with cochlear pathology with flat and moderate sensorineural losses. In another study, Bonding (1979) reported frequency selectivity and speech discrimination in sensorineural hearing loss. He reported that the PTCs rapidly deteriorated beyond normal limit values, when the hearing loss exceeded 30-40 dB (HL). Nearly the same dependency of the degree of the hearing loss was demonstrated for speech discrimination scores and a significant correlation was present between this score and cochlear tuning, as expressed by the PTC. Dubno and

Schaefer (1992) reported that the frequency selectivity was poor for the hearing impaired listener, and so was the consonant recognition scores.

g. Psychophysical tuning curves (PTCs) and aided speech recognition scores (A-SRS) for the experimental group:

Pair samples of EG	Correlation	Significance
Q_{10} 500 Hz and A-SRS	0.287	0.491
Q_{10} 1000 Hz and A-SRS	0.478	0.278
Q_{10} 2000 Hz and A-SRS	0.234	0.576
Q_{10} 4000 Hz and A-SRS	-0.056	0.928

Table 7: Paired samples correlation of Q_{10} of the PTCs and A-SRS for experimental group (EG).

The main aim of the study was to investigate the relationship between the aided speech recognition scores and psychophysical tuning curves. The results indicated that there was a positive correlation of 500 Hz, 1000 Hz, 2000 Hz and a negative correlation of 4000 Hz with A-SRS. The correlation obtained were not significant, but shows positive trend. Data with more subjects might reveal conclusive findings.

As it has been mentioned earlier, there was no significant difference between the aided SRS and the unaided SRS, but the difference between SRS of the control group and the aided SRS of the experimental group was significant. The amplification did not help in minimizing the difference between the control group SRS and the experimental group SRS. Thus, it can be inferred that just audibility is not suffice, but improvement in hearing aid technology to aid the frequency selectivity of the impaired cochlea is required.

For more definitive inferences, further studies have to be carried out with more number of subjects in the experimental group so that a trend for correlation could be set. Subjects with conductive pathology and subjects with different degrees of hearing loss would throw more light on the role of frequency selectivity of the cochlea and thus the SRS.

Implications of the study:

1. The sharpness of the tuning curves can be used for grading the hearing aid users as successful or unsuccessful.
2. The information from the psychophysical tuning curves can be used in improving hearing aid technology so that there is an improvement in the speech recognition scores with the hearing aids. This would inturn help in frequency resolution of the signal.

Suggestions for future research:

1. The number of subjects can be increased in the experimental group to obtain more conclusive results.
2. Psychophysical tuning curves for high-and low-frequency probes can be compared with speech intelligibility performance for high- and low-consonant vowel syllables.
3. Psychophysical tuning curves for different types, degree and configurations of audiogram can be obtained and can be compared with aided performance.

SUMMARY AND CONCLUSION

Auditory frequency analysis refers to the ability of the auditory system to separate the components in a complex sound. The impaired capacity for speech discrimination in patients with a cochlear hearing loss is mainly a consequence of a deteriorated frequency selectivity (Evans, 1975; Scharf, 1978). The frequency selectivity can be determined using psychophysical tuning curves (PTCs). It is a curve showing the level of a narrow band masker needed to mask a fixed sinusoid signal plotted as a function of masker frequency. In the literature, a number of studies report that the speech recognition scores correlate with the sharpness of the psychophysical tuning curves (Bonding, 1979). However, there have been few reports on the correlation of the psychophysical tuning curve with the aided speech performance. Therefore, the present study was carried out to investigate the relationship between the psychophysical tuning curves and the speech recognition scores in patients with cochlear pathology using hearing aids.

In the present study, two groups were taken, the control group and the experimental group. The control group consisted of 30 otoscopically normal ears with hearing thresholds less than or equal to 20 dB HL. The experimental group consisted of ten ears of ten subjects, with acquired sensori-neural hearing loss, ranging from moderate to moderately severe in degree and the audiometric slope of not more than 12 dB rise or fall per octave. The duration of hearing impairment was not more that 2 years and the subjects were naive hearing aid users. The age of the subjects ranged from 18 years to 55 years irrespective of gender.

The pure lone audiogram was initially obtained, and for ruling out retro cochlear pathology, supra threshold adaptation test (STAT) was administered. Speech audiometry was then carried out comprising of speech reception threshold (SRT) and speech recognition scores (SRS). Immittance evaluation comprising of tympanometry and acoustic reflex threshold (ART) was done. Psychophysical tuning curves were then plotted for 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz using a dual channel audiometer. After obtaining the psychophysical tuning curves, Q_{10} values were established for each frequency For the experimental group the selection of hearing aid was done using Insertion Gain Measurement (IGM), using the POGO procedure. After selecting an appropriate hearing aid, aided speech recognition threshold was obtained at 40 dB HL, in the sound field for checking the performance with amplification.

The following observations were made from the analysis of the results:

1. There was a significant difference (<0.05) between the Q_{10} values obtained from psychophysical tuning curves at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz for the control and experimental group. The psychophysical tuning curves for the control group were sharper and narrower compared to the psychophysical tuning curves for experimental group where the psychophysical tuning curves were broader and flatter.
2. There was a significant difference (<0.01) between the speech recognition scores of the control group and the unaided SRS of the experimental group. The speech recognition scores for the control group were better than that of the experimental group.
3. There was a significant difference (<0 01) between the speech recognition scores of the control group and the aided speech recognition scores of the experimental group. The aided speech recognition scores for the experimental group were poorer than that of the control group.
4. There was no significant difference (>0.05) between the unaided speech recognition scores and the aided speech recognition scores of the experimental group. This indicated that providing an appropriate hearing aid helps in improving the audibility but not the speech recognition scores in hearing impaired group.

5. There was a correlation between the psychophysical tuning curves and the speech recognition scores of the control group. The correlation obtained between the PTCs at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and SRS was 0.056, 0.218, 0.075, and 0.018 respectively.
6. There was a correlation between the psychophysical tuning curves and the unaided speech recognition scores of the experimental group. The correlation obtained between the PTCs at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and unaided SRS was 0.36, 0.23, 0.34, and -0.33 respectively. Only at 4000 Hz there was a negative correlation.
7. There was a correlation between the psychophysical tuning curves and the aided speech recognition scores of the experimental group. The correlation obtained between the PTCs at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and aided SRS was 0.28, 0.47, 0.23, and -0.56 respectively. Only at 4000 Hz there was a negative correlation.

The correlation obtained was positive but not significant (>0.05).

From the results, it can be inferred that the psychophysical tuning curves in the cochlear pathology group correlates with the unaided speech recognition scores. However, the correlation was not significant. This information about correlation of the psychophysical tuning curves and aided speech recognition scores will help to determine the benefit the user is going to obtain from the hearing aid.

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