USEFULNESS OF TRANSCRANIAL C.R.O.S. FOR CLIENTS WITH UNILATERAL HEARING LOSS

Pawan Kumar Sah

Reg.No.MSHM0114

A Dissertation submitted in part fulfillment of the
Master's Degree, (Speech and Hearing),
University of Mysore,
Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING,
NAIMISHAM CAMPUS, MANASAGANGOTHRI,
MYSORE - 570 006

JUNE - 2003

Dedicated to

My wife "Sangi"
Whose selfless love and
constant encouragement made
it all possible

CERTIFICATE

This is to certify that this dissertation entitled **"USEFULNESS OF TRANSCRANIAL C.R.O.S. FOR CLIENTS WITH UNILATERAL HEARING LOSS"** is a bonafide work in part fulfillment for the degree of **Master of Science** (Speech and Hearing) of the student (Register No.MSHMOl 14).

Director
Dr. M. Jayaram
All India Institute of Speech and Hearing
Mysore - 570 006

Mysore
June, 2003

CERTIFICATE

This is to certify that this dissertation entitled **"USEFULNESS OF TRANSCRANIAL C.R.O.S. FOR CLIENTS WITH UNILATERAL HEARING LOSS"** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier in any other University for the award of the Diploma or Degree.

Guide
Ms. P. Manjula
Lecturer in Audiology
Department of Audiology
All India Institute of Speech and Hearing
Mysore - 570 006

Mysore,
June, 2003

DECLARATION

This dissertation entitled **"USEFULNESS OF TRANSCRANIAL C.R.O.S. FOR CLIENTS WITH UNILATERAL HEARING LOSS"** is the result of my own study under the guidance of **Ms. P. Manjula,** Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and not been submitted earlier in any other University for the award of any diploma or degree.

Mysore

June, 2003

Reg. No. MSHMO114

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my guide Ms. P. Manjula, Lecturer, Department of Audiology, All India Institute of Speech and Hearing, for her valuable suggestions and guidance throughout my work Mam, I thank you for patiently shaping my efforts.

I thank Dr. M. Jayaram, Director, All India Institute of Speech and Hearing for permitting me to carryout this study.

I thank Dr. Asha Yathiraj, HOD, Department of Audiology for allowing me to use the instruments necessary for my study.

I owe my thanks to Animesh Sir for his suggestions and constructive criticism.

I would like to express my heartfelt thanks to Poornima, Srividya, Dhanalakshmi, Satisha and Ms. Dakshayani for helping me find my cases.

Dear classmates (Yo!!), I will always treasure my memories which you people have made, sweet. . . .

Dear Krishna Sir, I consider myself lucky to have your guidance and being continuous source of inspiration.

Thanks to all my juniors, especially B.K.C., Moumita, Viji, and Yatin for being such lovely friends.

I express my gratitude to all my clients for their co-operation, your support has not only helped my dissertation but also future patients.

Dear Sunita, Sujita and Sukant you are among my good pals, thanks for your good wishes which really worked out.

Dear Sai, I would life to thank God, for sending you as my friend and I am sure that we will really rejoice the time which we spent together...

Dear Manoj, our friendship has given me a lot of strength and I am sure it will increase thousand folds.

Dear Rahul, Arzoo, Dikshya and Kajal, you all have added colour in our life.

Dear Bhaiya, Bha6hi, Didi and Jiju, your contributions in my life are unforgettable.

Maa and Ba6uji, your love, care and faith on me have helped me reach this point.

Dear Sangi, thank is not the right word for me to express my feelings for you. I wish "If I got a chance to live my life again, I would want it in the same way, I would wish you as my life-mate again to re-experience the ecstasy of falling in love again...."

Nothing moves in the world without devine will. No amount of thankfulness or gratefulness would suffice the expression, I have for you, dear GOD.

TABLE OF CONTENTS

INTRODUCTION

Hearing loss often has been called the "invisible condition", yet its impact may be anything but invisible. The consequences of hearing loss may be manifested in a broad spectrum of an individual's life. For example, everyday communication may be difficult, and, for some persons, impossible without a great deal of effort. The adult may feel the ramification of hearing loss at home, in the workplace, and in the community. The young child may share similar difficulties in everyday communication, and may also experience delays in speech, language, social developments and educational achievements.

Aural rehabilitation is designed to help individuals overcome the challenges posed due to hearing impairment with appropriate technical support and then develop the individuals' skill levels step-by-step. The fundamental goal of aural rehabilitation is to alleviate the difficulties related in hearing loss and to minimize its consequences.

Generally, unilateral hearing loss can be defined as hearing impairment in one ear and normal hearing (15 dBHL or better from 250 to 8000 Hz) in the opposite ear. If the hearing impairment is mild to moderate, the individual often does not experience difficulties in communication. But if the loss in the poorer ear becomes severe to profound, it manifests serious impact on the individual's life as a whole. Unilateral profound hearing impairment constitutes both medical and social problems (Culbertson & Gilbert, 1986). From the medical point of view, there may be a problem of early diagnosis of unilateral deafness, especially in children, when on numerous occasions the early childhood unilateral hearing loss are recognized only at the beginning of school. It is then difficult to establish the duration of deafness and its etiology (Brookhouser, Worthington & Kelly, 1991; Tarkkanen & Aho, 1966).

Bess and Tharpe (1986) have quoted prevalence rate of unilateral hearing loss in school aged children of 3:1000, in which loss was 45 dB or greater. However, Marttila, Vartiainen and Karjalainen (as cited in Pruszewick, Obrebowski, Woznica, Sekula, Swidzinski, & Karlik, 2001) conducted studies in Scandinavian countries over a number of years, and reported that the number of cases with unilateral deafness is decreasing due to preventive measures such as the introduction of vaccination against mumps and measles. Prevalence of permanent unilateral hearing loss is estimated to be approximately 2 per 1000 among school age population. Miller (1989) has reported unilateral hearing loss in 3% of the population in US.

Everberg (1960) sampled 122 cases of unilateral hearing loss. There was a greater prevalence of affected males (62 %) than females (38 %). Etiology was unknown in about half the cases. Bess and Tharpe (1986) stated that heredity is the most common congenital factor, however, it is widely thought that unilateral losses arise chiefly from postnatal condition, in particular from viral infections (especially mumps) and meningitis. Of the sixty unilaterally impaired children (hearing loss in the impaired ear greater than 45 dBHL), studied by Bess (as cited in Bess and Tharpe, 1986) the etiology was unknown in 51 percent, viral complications in 26 percent, meningitis in 13 percent and head trauma in 8 percent of the cases. Of interest is that unilateral hearing impairment is generally detected in later life, since speech and language appear to develop more or less normally. Tarkkanen and Aho (1966) have given an average identification age of 6 yrs for unilateral hearing loss. There are evidences that speech articulation also can be affected if the loss occurs in very young children.

Learning disability can be directly related to the unilateral hearing loss. Pruszewicz, et al., (2001) found in their study that in most of examined children with unilateral deafness, the moment of deafness diagnosis was accidental not dependent on its onset and degree. Research continues to reveal that children with unilateral hearing loss are at a higher risk for grade failure. Two recent clinical reports suggested that at least 25% of these youngsters repeat one or more grade, especially if the loss is severe - profound and / or is in the right ear (Bess & Tharpe, 1986). Clients with unilateral hearing loss can present a challenge to rehabilitation audiologists in many ways. Firstly, the hearing loss in the bad ear is usually so severe that amplification cannot provide satisfactory word recognition. Secondly, there is typically a marked reduction in dynamic range. In addition, because of normal hearing in the other ear, client often reports little or no benefit from amplification because the good ear is capable of receiving speech cues at normal sensation levels. The social problem in such clients is the right to receive disability benefit. In these cases of unilateral deafness, in view of the present certification rules, there remains only the possibility of receiving rehabilitation benefit.

According to The Persons With Disability Act (1995) "hearing impairment" means loss of sixty decibels or more in the better ear in conversational range of frequencies.

Individuals with bilateral hearing loss, either congenital or acquired, make an early attempt to seek professional help and they do accept the mode of treatment. Unilateral hearing impairment may often go unnoticed. This may be because the child can function fairly well with normal hearing in one ear only. Even in the case of unilateral atresia, the possibility of a mild or moderate impairment in the good ear should not be ignored. When a child has near-total loss in one ear, any mild or moderate hearing impairment in the better ear, perhaps from an ear infection, can be expected to create serious problems in the area of psychological, linguistic and educational skills if it is untreated for more than a brief period (Culbertson & Gilbert, 1986).

A severe to profound unilateral hearing impairment is likely to create problems in localizing sounds and speech, and to make comprehension difficult in noisy environments. Giolas & Wark (1967) have documented communication problems associated with unilateral hearing loss, which was primarily based on an interview with persons with monaural hearing. It has been observed that persons with a unilateral hearing loss have difficulty understanding speech and localizing auditory stimuli, in both quiet and noisy setting, with noise being the single most contributing factor creating a difficult listening situation. In quiet settings, distance appeared to be the most common factor. It has been also reported that persons with a unilateral hearing loss have specific feelings of general negative nature about difficult listening situation they experience. These feelings occur most often when it is necessary to explain the nature of their loss to a stranger.

Rehabilitative approach to clients with unilateral hearing loss is preferential positioning of the normal ear to face the desired signal, speech reading and preventing hearing loss in good ear. This approach includes counseling the clients on the problems associated with unilateral hearing loss, i.e., head shadow effect, loss of such binaural advantages as the squelch effect, binaural summation, localization and prevention of hearing loss in better/ normal ear. This approach has limited advantages in certain situations, e.g., the consequence of this approach for a client who has normal hearing in the right ear, driving a car, needs to converse with a passenger on left side is not favourable.

Harford and Barry (1965) introduced contralateral routing of signal (CROS) successfully, for helping clients with unilateral hearing loss, to overcome the head shadow effect. In the earliest version, CROS amplification consisted of a microphone placed over or near the unaidable ear to pick up signals arriving at the side of impaired ear. The output from the microphone was wired to an amplifier and receiver via a tubing gently placed in the open ear canal of the good ear. Different variations of CROS have been used to meet the needs of hearing impaired individuals.

To solve the problem of wiring, wireless BTE CROS hearing aid was introduced in 1973, but still requires two separate units. CROS amplification effectively eliminates the head shadow effect and aids in localization to some extent but speech intelligibility in noise still remained a problem. Also clients using CROS have reported that the amplified signals sounded harsh and unpleasant (Valente, 1995). Moreover uses of CROS, especially with younger children have not been encouraging in many cases.

Transcranial CROS (T-CROS)

To overcome the problems associated with using traditional CROS amplification another option, i.e., T-CROS, was advocated by several authors (Sullivan, 1988; McSpaden and McSpaden, 1989; Miller, 1989; McSpaden, 1990; and Chartrand, 1991). The concept of T-CROS is entirely different from those of conventional CROS. Transcranial CROS means to couple a high gain / high output ITE or BTE hearing aid to poorer (bad) ear, not with the intention to aid that ear but, to allow the amplified signal to transfer to the cochlea of better ear by bone conduction, through the internal cross over. Because the signal picked up by a microphone placed in the impaired ear is transferred to the cochlea of the good ear through the cranial structures of the temporal bone (Sullivan, 1988; McSpaden & McSpaden 1989; Miller, 1989; McSpaden, 1990; and Chartrand, 1991), this type of fitting is referred to as a "transcranial CROS". This fitting is also called "internal CROS".

Sullivan (1988) described the successful application of the principle using high gain full shell ITE instrument fitted to the deaf ear. Sullivan (1988) demonstrated improved receptive communication in a variety of listening situations.

Also reported was a perceived improvement in sound localization ability, apparently due to qualitative differences between the bone conducted sounds originating from the deaf side of the head and air conducted signals arriving at the unaided normal ear. The single unit has serious limitation when the better ear has reduced sensitivity to a level of 35 dB or more.

Valente, Potts, Valente and Goebel (1995) have developed a fitting strategy that involves using the real-ear measure to determine if the aided signal is loud enough to exceed the unaided transcranial threshold. The clients who were prescribed the hearing aid by this procedure have reported benefits in terms of a more natural sound, improved localization and improved listening in noise when the signal faced the aided ear. Apart from these benefits, the client needs to manage only one unit that requires one cell, thus cost effective than the conventional CROS or wire less CROS. Secondly, it facilitates telephone communication, as the better ear is free from being occluded.

NEED FOR THE STUDY

Rehabilitative approach to clients with unilateral hearing loss is usually counseling in order to orient the better ear towards the desired signal source. However, this does not hold good in all situations and for all clients. In literature, CROS amplification and its variations have been advocated to these clients. Also some clients have shown benefit, where as others have reported limited usefulness with the CROS and its variations. Sullivan (1988) advocated T-CROS for such clients. There is a dearth of studies to support the usefulness of transcranial CROS.

Hence, it is required to investigate the usefulness of transcranial CROS in clients with unilateral hearing loss.

AIMS OF THE STUDY

To investigate the usefulness of transcranial CROS (T-CROS) in clients with unilateral hearing loss, the following were the aims of the study:

To compare the unaided and aided performance on the following:

a. Speech recognition score (SRS) in the presence of noise.

b. Localization in the horizontal plane.

c. Communication ability on telephone.

REVIEW OF LITERATURE

Communication through speech is dependent upon various factors and the most important factor among these is "the sense of hearing". Hearing or audition may be thought as general understanding or awareness of an individual about his surrounding environment. Hearing is based on the processing of information received through two ears. Binaural hearing is based on ability of the total human system to detect two different signals, analyze their differences and perceive a single auditory image. Loss of hearing brings about adverse effect on these aspects. Martin and Clark (1975) defined hearing loss as "any loss of sound sensitivity, partial or complete, produced by abnormality anywhere in the auditory system". There are various modes of rehabilitation of the hearing impaired individual.

The review of literature is being discussed under following headings:

1. Problems faced by unilateral hearing loss clients.
2. Use of hearing aids by unilateral hearing loss clients.

1. *Problems faced by unilateral hearing loss clients*

The ability of a listener to perceive and organize his auditory environment depends partly on the use of two ears and the resulting neural interactions that occur between the binaural signals as they progress through the auditory pathways. Koenig (1950) asserted that binaural hearing offered the following advantages over monaural hearing.

a) A remarkable ability to "squelch" reverberation and background noises.

b) The power to select one stimulus from a number of stimuli, as it were to "tune in" to one sound source or one person, the "Cocktail party effect", and

c) To understand speech under extremely unfavourable signal to noise ratio.

Bergman (1957), Groen and Hellema (1960) and Mackeith and Coles (1971) supplemented the above advantages with the following:

a) Enhanced localization.

b) Summation of energy, both at threshold and at supra threshold levels.

c) Summation of information content especially when the hearing losses in the two ears are dissimilar in frequency distribution / configuration.

d) Avoidance of head-shadow, especially when listening with a background noise.

e) Better discrimination of speech in quiet and in noise.

f) Ease of listening

g) Better quality of sound.

It is well established that the binaural threshold of hearing, for pure tone, is more sensitive than the monaural, the difference being 3 dB (Keys, Shaw, Newman & Hirsh; Pollack, Reyonolds & Stevens, as cited in Markides, 1977). They also have found that the binaural threshold for speech in quiet,was 3 dB more sensitive than the monaural threshold. Pollack and Pickett (1958), further demonstrated that binaural summation of speech in noise can occur even when the signal levels at the two ears differ by as much as 25-30 dB. Coles (as cited in Markides, 1977) stated that a 20 dB difference between the ears has little effect on binaural summation of speech and even with a 40 dB difference the weaker ear still contributes significant information.

It is true that a 3 dB gain at threshold can hardly be considered an advantage for normally hearing people for they seldom need to listen to speech at threshold level. Hearing impaired people, however, often find themselves listening to speech at threshold level. It is obvious, therefore, that for such people, a few dB gaint at threshold can be a very real advantage.

Bocca (1955) and Groen and Hellema (1960) using speech discrimination procedures, found that the binaural and monaural curves run parallel to each other, indicating that a higher level is required for monaural listening to achieve the same articulation score as during binaural listening.

Tillman, Kasten and Horner (1963) studied the effect of head shadow on speech intelligibility and they found that the head shadow effect attenuated the sound field spondee threshold by 6.4 dB for normal listeners positioned between two loudspeakers located at 45° on either side of the midline of the head.

Hirsh (as cited in Markides, 1977) suggested that directional hearing facilitates the intelligibility of speech, especially in the presence of noise and that slight head movements give sufficient localizational clues to a monaural listener, thus eliminating the advantages of the binaural squelch and head-shadow effects. Due to the binaural advantages as mentioned earlier, a binaural listener can cope with difficult listening environments (the cocktail party effect) much more effectively than his monaural counterpart.

Experimental evidence suggests that the incoming auditory information is first analyzed separately by each ear and secondly cross analyzed as described by Cherry (1961). The cross correlation facility enables the binaural listener to use interaural signal differences in temporal and intensity characteristics as cues to increase efficiency in binaural reception especially in the presence of noise (Cherry and Sayers, 1956). These children with unilateral hearing impairment typically have problem in one or more of the following areas:

- Difficulty locating the source of sounds.
- Difficulty understanding speech in a background of noise particularly if the "good" ear is close to the competing signal.
- Difficulty maintaining attention and following classroom instruction and discussion, especially if it is noisy.
- Difficulty with schoolwork particularly with language based subjects (reading, writing, spelling, etc).

In order to minimize these potential problems the following guidelines are usually recommended as a management strategy:

- Monitor the child's hearing status at least annually and be alert for any problem related to ear.
- Protect good ear from damage and avoid loud sounds.
- Avoid dangers, crossing busy streets, riding bicycles in heavy traffic.
- Use of rear view mirror on bicycles/vehicles and careful training in street crossing is needed.
- During communication the child's good ear should be favoured.

- In classroom situation, a structured environment with least amount of noise and reverberation should be provided.
- As children with unilateral hearing loss are at risk for grade failure, regular monitoring of classroom performance and academic achievement should be done.
- Amplification options should be considered if the child is found to have a speech language delay or problem in classroom performance.

2. The use of hearing aids with unilateral hearing loss clients

From the audiological point of view, unilaterally hearing impaired people can be divided into two groups. Group one includes those patients with a slight monaural hearing impairment who can be expected to receive benefit from a hearing aid in their bad ear (poor ear). Group two includes those patients with very severe or total monaural hearing loss who are not expected to receive any benefit from a hearing aid. Bergman (1957) suggested that people included in the first group could benefit from amplification in their poor ear.

Binaural hearing with one hearing aid (BOHA)

Bergman, Haskins and Hardy (as cited in Harford & Musket, 1964) have suggested that unilateral hearing loss might benefit from a hearing aid to restore presumed benefits of binaural hearing. Malles (1963) reported improved discrimination in noise for eight unilateral hearing loss subjects when they wore hearing aids. Harford and Musket (1964) coined the term Binaural Hearing with One Hearing Aid (BOHA) for this device. They reported improved discrimination in three of eight aided unilateral hearing loss subjects when PB lists were directed towards their aided ears, in comparison with identical unaided condition.

In cases where the impaired ear cannot benefit from amplification a different approach was reported. It was Fowler (I960) who was the first to propose an ingenious hearing aid for such individuals. He suggested that such people could benefit from a hearing aid device fitted in the better ear and being fed simultaneously by a separate remote microphone located on the side of the poorer ear.

Wullstein and Wigand (1962) simplified Fowler's technique to better suit clients with total or near total unilateral hearing loss by omitting the microphone on the side of the good ear and making sure that earmould in the good ear was not usually interfering with the free access of sound. Thus, signals originating on the side of the affected ear were picked up by the microphone on that side, amplified slightly and then fed to the normal ear via an open earmould. They also reported considerable improvement in discrimination ability when using this system, especially in circumstances where speech was coming from the side of the impaired ear. They pointed out that this device had limited acceptance by the subjects tested.

Miller (1965), however, presented the case of a lady with unilateral hearing impairment who was successfully fitted with such an arrangement. Harford and Barry (1965) modified an air conduction ear level hearing aid on the principle put forward by Wullstein and Wigand (1962) and called it the CROS (Contralateral Routing of Signals) hearing aid. Such a hearing aid is placed behind the affected ear that electrically feeds the amplified signal across the head to a receiver mounted near the good ear. Then acoustic signals are fed to the good ear via a polyethylene tube inserted in an open earmould. The open earmould is an essential part of the CROS system since the good ear must be left unoccluded to allow normal reception of sound. Harford and Barry used their CROS system with twenty patients with unilateral hearing impairments and they reported encouraging results. They claimed, for example, that seventeen of the subjects, after using the CROS hearing aid, decided to procure one. Eight months afterwards, it was found that only seven of these seventeen subjects voluntarily bought such a hearing aid. They also claimed that most of the subjects reported better localization ability when wearing the CROS hearing aid. This they stated was possible because sounds originating on the side of the affected ear had a "metallic" or "unnatural" quality, while those from the good side had "normal" quality.

Harford and Dodds (1966) published a more extensive report on forty-five patients with unilateral hearing losses and stated that nearly 65% of them found the CROS system very helpful in their daily life activities.

Lotterman, Kasten and Revoile (1967) evaluated the CROS aid with twenty unilaterally hearing impaired persons. They tested the speech discrimination abilities of the subjects under the following listening conditions.

a) Speech direct (opposite the good ear) and noise indirect.

b) Speech direct and noise overhead

c) Speech indirect and noise direct

d) Speech indirect and noise overhead

The results showed that under the most favourable listening condition (speech indirect, noise direct), the aid provided a relative increase in articulation scores of 38% and in the least favourable condition (speech direct, noise indirect) a relative decrease of 25%. They concluded that although the CROS aid may provide some benefit to a unilaterally deaf person on certain occasions, it also under certain circumstances actually accentuates the problem.

MacKeith and Coles (1971) tested eight subjects with unilateral unaidable hearing loss using CROS, i.e., listening both with and without a CROS hearing aid in a non-reverberant environment. Speech was presented from the side of the bad ear (indirect listening) and noise from the side of the good ear. The test was conducted under S/N ratio at 0, +5, +10 and +20 dB. Results showed that the mean speech discrimination scores of the subjects achieved with CROS hearing aid when speech was presented from the side of the bad ear, were significantly higher than the mean scores achieved with the good ear, except at +20 S/N ratio, where no significant difference was observed. Also, when the performance;of the subjects with and without the CROS hearing aid were compared, in terms of difference in S/N ratio calculated at their respective 50% discrimination levels, it was found that CROS hearing aid showed a significant improvement of 5.13 dB over the monaural indirect performance.

Lotterman, Kasten and Revoile (1967) also reported similar results that CROS instrument was beneficial under the most favourable condition but under unfavourable condition the CROS aid actually reduced listening efficiency by introducing amplified background noise to the good ear. Similar conclusions were also reached by Tonning (1971).

Aufricht (1972), however, in a follow-up study of the CROS hearing aid issued to sixty unilaterally deaf male veterans in America, reported that of the fifty-four patients who returned their questionnaire, 85% wore the aid, liked it and derived benefit from it, only 15% did not like it. The author pointed out that most of the subjects found the CROS aid most disturbing in a noisy environment.

MacKeith and Coles (1971) conducted a study to check localization ability in six subjects with unilateral unaidable sensorineural hearing impairment, with and without CROS hearing aid, in a non-reverberant environment, without head movement. Their results showed that the subjects did not show any improvement in localization ability when fitted with the CROS hearing aid. According to the subjects, the speech sounded as if it was coming from "all over the place", "the ceiling" or it was just "in the ear".

It was also thought that a more efficient method of stimulating the cochlea of the normal ear would be via a bone conduction hearing aid. Whereas, 30 dB to 50 dB of gain is necessary for the output from an air-conducted signal to reach the cochlea of the normal ear, minimal gain is required for a signal delivered via a bone conduction hearing aid. Testing a similar hypothesis, Weber, Roush and McElveen (1992) reported no improvement in word recognition scores or localization skills for eight subjects with unilateral profound hearing loss who were fitted with a Xomed bone conduction hearing device implanted to the "dead" ear.

Valente (1995) prescribed eyeglass bone conduction hearing aid to seven subjects with unilateral sensorineural hearing loss. Out of them six subjects purchased the hearing aid after 60 days trial. Although success was reported with this small group, fitting eyeglass presented significant obstacle. These included:

1. Elimination of amplification when the eyeglasses are removed.
2. Significant difficulties in finding an optician knowledgeable in the proper placement of the bone vibrator on the mastoid process, and
3. Discomfort and, in some cases, pain, resulting from the pressure on the mastoid process that is necessary for this fitting to be successful.

CROS amplification effectively eliminates the head shadow effect and helps in localization to some extent but speech intelligibility in noise still remained a problem. Also clients using CROS have reported that the amplified signals sounded harsh and unpleasant (Valente, 1995). Harford and Barry (1965), Harford and Dodds (1966) and Punch (1988) have emphasized on one point regarding CROS amplification that the success with CROS amplification is significantly related to the magnitude of hearing loss in the good ear. If hearing in the good ear is within normal limits, then the probability of success with CROS amplification will be minimal. On the other hand, if a mild hearing loss is present above 1500 Hz, then a greater probability of patient acceptance will be achieved.

Transcranial CROS

Another approach to providing benefits of amplification to unilaterally hearing impaired has been advocated by several authors (Sullivan, 1988; McSpaden and McSpaden, 1989; Miller, 1989; McSpaden, 1990; and Chartrand, 1991). They suggested placing a high gain - high output ITE or BTE hearing aid into the impaired ear to take advantage of the fact that the cochleae for each ear, which are contained within the temporal bone, are not acoustically isolated. That is, if a signal of increasing intensity is presented to the cochlea of an impaired ear, the signal will eventually be heard in the cochlea of the better ear because it will be intense enough to overcome the acoustic isolation (interaural attenuation) between the cochlea of two ears. Because the signal picked up by a microphone placed in the impaired ear is transferred to the good ear through the cranial structures of temporal bone, Chartrand (1991), McSpaden (1990), McSpaden and MacSpaden (1989), Miller (1989) and Sullivan (1988) referred to this type of fitting as a "transcranial CROS ".

Sullivan (1988) and Miller (1989) have reported that transcranial fittings provide

a. A more natural sound,
b. Improved word recognition in noise when signal faces the impaired ear,
c. Improved localization
d. Less harsh sound quality than with conventional CROS.
e. A greater willingness to wear a single unit rather than two units.

Other reports by McSpaden (1990), McSpaden and McSpaden (1989), and Sullivan (1988), indicated that listeners found transcranial CROS fittings "more natural", provided localization via cues from metallic sound from the aided side and a natural sound from the normal side, and improved listening in noise when the signal was from the impaired ear side. Patients did not report the harshness that some experience with CROS fittings.

Valente, Valente, Meister, Macauley and Vass (1994) in "Selecting and verifying hearing aid fitting for unilateral hearing loss" evaluated twelve patients with unilateral profound sensorineural hearing loss. For each patient a strong ITE hearing aid (maximum SSPL of 120 dB; full on gain of 55-65 dB) with a long canal and pressure vent was fitted to the impaired ear. Four patients were experienced users of CROS amplification to the better ear. Two patients had experience with eyeglass bone conduction hearing aid placed on the mastoid process of the impaired ear. Five patients had no experience with amplification, and one patient had experience with a mild ITE hearing aid coupled to the better ear. At the end of four weeks, half of the patients felt that the ITE transcranial CROS provided significant benefit, while the other half noted little additional benefit and decided to continue to utilize their current hearing aids or not to pursue amplification. However, it has not been mentioned that out of five patients who appreciated the benefit, how many of them were experienced users of hearing aid.

Valente (1995) has reported the acceptance rate of CROS was 10% while the acceptance rate for transcranial CROS was 50% and the reason for rejection of transcranial CROS by many of the patients were related to feed back or to a sensation of vibration generated from the hearing aid.

METHOD

Subjects

Eleven clients (six males and four females) in the age range of 13 to 55 years were included in the study.

All the clients fulfilled the following criteria:

1. Unilateral sensorineural hearing loss, i.e., unaidable hearing in one ear and normal hearing (20 dB HL or better in octave frequencies from 250 Hz to 8 kHz) in the other ear.
   a. Unaidable hearing was defined as an ear having one or more of the following characteristics.
      - Severe - to - profound sensorineural hearing loss, so that amplified sound cannot be heard to any degree of usefulness.
      - Very poor word recognition score.
2. Should not have indication of middle ear or retrocochlear pathology.
3. Should not have any contraindication to use hearing aid.
4. Should be verbal, with spoken knowledge of Kannada.
5. Should be first time hearing aid user.

Instruments

- A calibrated diagnostic audiometer (Maico MA 53) with sound field facility was used for establishing AC and BC hearing thresholds, to rule out retrocochlear pathology, to establish transcranial thresholds (TCTs) and speech recognition scores.

- A calibrated GSI Tympstar immittance meter was used to rule out middle ear pathology.
- Fonix 6500 C, real time analyzer, was used for the measurement of Transcranial Thresholds (TCTs) and Real Ear Insertion Responses (REIRs) for hearing aid selection.
- Hearing aids (BTE hearing aids of high gain) with stock ear mold.
- Telephones

Test environment

Evaluation was carried out in an air conditioned sound treated double room suite in which, the ambient noise levels were within permissible limits (re: ANSI 1991, cited in Katz, 1994).

Procedure

The following measurements were carried out to evaluate the usefulness of transcranial CROS:

A. To select a hearing aid based on TCTs, the following steps were adapted:

Step 1: Measurement of transcranial thresholds (TCTs)

Step 2: Selection of hearing aid

B. Sound field evaluation:

a) Speech recognition scores in presence of noise, in the direct and in the indirect conditions.

b) Horizontal plane localization.

C. Performance on telephone conversation in quiet:

A. To select a hearing aid based on TCTs, the following procedure was adapted:

Step I: Measurement of transcranial thresholds (TCTs)

- Sound field was equalized after probe tube was calibrated.
- The loudspeaker and reference mic were disabled.
- The probe tube was placed in the ear canal of poorer ear at a predetermined length (3-5 mm more than the length of ear canal of ear mould selected for the individual client).
- An insert phone (ER-3A), coupled with an appropriate sized probe tip, of a calibrated audiometer (Maico MA 53), was placed in the canal of the poorer ear along with the probe tube in place.
- Pure tone was presented from the audiometer at octave and mid-octave frequencies (250 Hz to 8kHz). The client was instructed to respond for pure tones to find out his thresholds. With this signal in the ear canal, the SPL in the ear canal was measured by the probe tube mic of the Fonix 6500 C system. The unmasked thresholds were recorded at octave and mid-octave frequencies, by recording the SPL values from monitor. These were the transcranial thresholds (TCTs). The TCT is defined as the minimum level of pure tone, measured by probe tube mic, at which the client detected the presence of the tone more than 50% of the time.

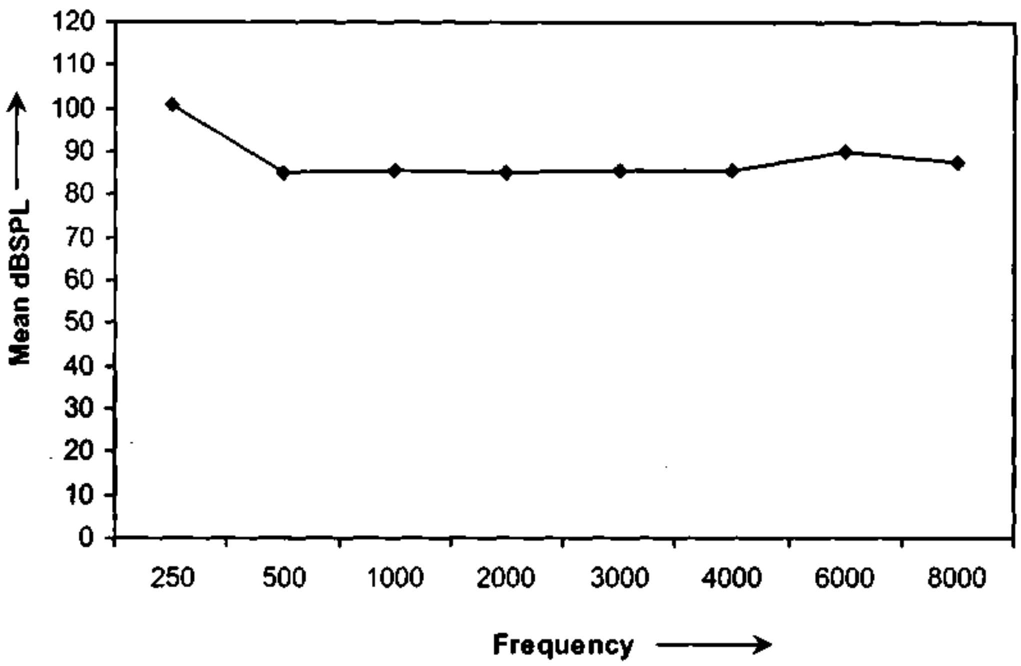


Figure 1 : Average TCTs in dB SPL measured near the eardrum from 250 to 8 kHz.

Instructions

Instructions given to the clients were similar to that while finding out the thresholds of hearing conventionally, i.e., they were instructed to raise their finger whenever they heard a pure tone, even if it was faint, irrespective of ear in which they heard. Thus, recorded unmasked thresholds represented the TCTs, which served to determine the target gain.

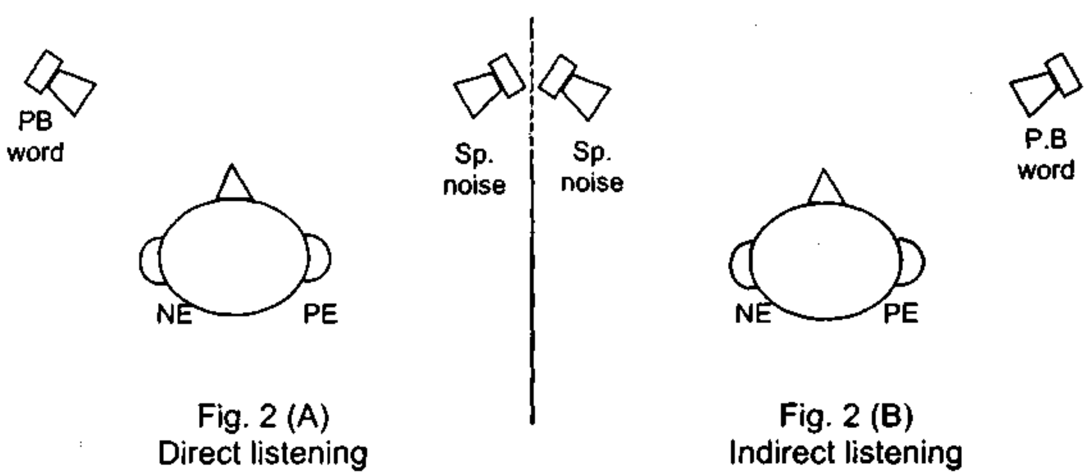
Step 2: Selection of hearing aid

- The sound field was equalized (leveled) after ensuring that the measuring system was in calibration.
- From the probe menu "create target" was selected.
- The TCTs were fed in.

- The NAL-R prescriptive formula was selected.
- The target gain at different frequencies was thus obtained on the Insertion Gain monitor.
- The Real Ear Unaided Response (REUR) was recorded by presenting the composite signal at 60 dB SPL and measuring the SPL in the open ear (of the poor ear) by means of the probe tube mic inserted with predetermined length.
- The Real Ear Aided Response (REAR) was then recorded with the 2 or 3 pre-selected hearing aids. The hearing aid, with appropriate settings, whose Real Ear Insertion Response (REIR) best matched the target gain curve was the one that was selected for each subject.

B. Sound field evaluation:

a) Speech recognition scores in presence of noise, in the direct and the indirect conditions



NE = Normal ear, PE = Poor ear

Fig 2. A: Arrangement for direct listening. B: Arrangement for indirect listening.

The physical arrangements for the administration of the free field speech recognition test are shown in Figure 2 (A and B). The client was seated comfortably on a chair at one meter distance and 45° azimuth from loud speakers of the audiometer.

SRS for each client was established using the following steps:

Step 1: PB word list (List A and List B) in Kannada, developed by Vandana (1998), was presented at 50 dBHL through the loudspeaker from the side of normal ear, and speech noise was presented at same level, through the loudspeaker from the side of poor ear (Fig. 2A). The client repeated the words presented and the number of correct responses were tabulated.

Step 2: The position of the client being the same, the loudspeaker output was reversed (Fig 2.B), so that speech signal (PB words) was presented from the side of poorer ear while speech noise arrived at the side of normal ear.

List A and List B, of 50 words each, were randomly presented in the direct and the indirect conditions for each subject in unaided and aided conditions, to avoid the order effect.

Instructions

For both direct and indirect conditions the client was instructed as follows:

"You arc going to hear certain words. You will also hear, at the same time, a continuous hissing noise. Please listen carefully to the words, ignoring the noise. Repeat after each word what ever you think you heard, without moving your head / body".

Scoring

In each of the conditions, the number of words correctly repeated by each client was recorded. These unaided and aided speech recognition scores were expressed as a percentage score based on number of words correctly repeated. The percent score for each condition was tabulated for each client for the statistical analysis.

b) Horizontal plane localization

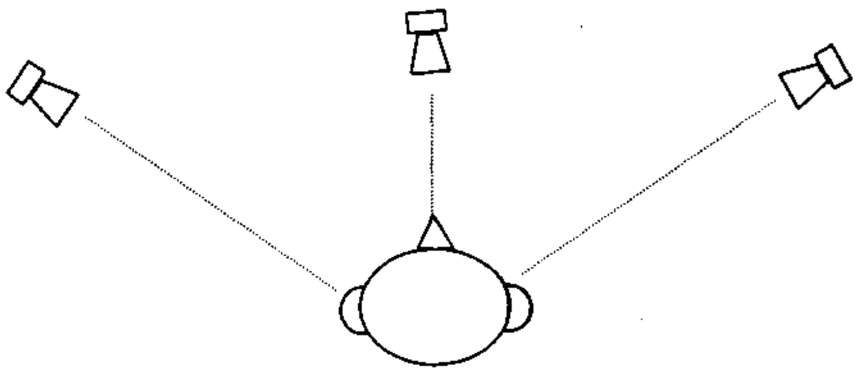


Fig. 3: Arrangement of speakers for localization.

The client's ability to localize speech noise presented at comfortable level, from two different directions was examined. As shown in Figure 3, the client was seated in the same arrangement as for the SRS testing arrangement, in addition, one extra loudspeaker was located in the center of the two loud speakers, i.e., at 0° azimuth from one meter distance. This speaker was functionally disabled, with an intention of confusing the client so that it will minimize the chance response.

Step 1: Ten bursts of speech noise (2 to 3 seconds duration) were presented one after another, from the audiometer, through the speakers (one speaker at a time) in a random order. The presentation of bursts was such that the speech noise was presented five times from the right loud speaker and five times from the left loudspeaker. The presentation was randomized from right and left speakers.

Step 2: Similar to step 1, the bursts of speech noise were presented in aided condition.

Instructions

Each client was instructed as follows:

"There are totally three speakers kept in front of you - on your left, center and right. You are going to hear some noise for 2 to 3 seconds duration, which is given through any one of the speakers at a time. Please listen carefully, each time, without moving your head / body and point to the speaker through which you heard the noise.

Scoring

For each subject, in unaided and aided condition, incorrect identification or localization out of 10 presentations was recorded. The localization of noise source to the center loudspeaker was also considered incorrect.

Total number of incorrect responses was subtracted from the total number of stimuli presented (i.e., 10). The scores for each client could range from 0 to 10 for correct identification. Thus, the correct localization responses were, for each client, tabulated for further statistical analysis.

C. Performance on telephone conversation in quiet

The client was seated comfortably on a chair, near a telephone (Siemens - Beetel 802) kept on a table in front of the client.

Instructions

Each client was instructed as follows:

"There will be a call from this telephone. You will have to receive the phone call in the poorer ear. You will be asked a few questions for which you have to answer".

Step 1: A set of five questions related to the daily activities was asked through the telephone meant for intercom. The questions were asked at a normal speaking rate and normal loudness level by the tester. The number of correct answers in the unaided condition was recorded for each client.

Step 2 : The best suited hearing aid, which was selected for each client, was kept at T-position and the volume control wheel was slightly increased from the use gain setting. The same procedure as of step 1 was repeated and the number of correct answers in the aided condition was also recorded for each client.

Scoring

The maximum score a client could achieve was five and minimum score was zero. Scoring was accomplished for both unaided and aided conditions for each client.

The data recorded during the Insertion Gain Measurements, Sound Field evaluations and Evaluation of telephone performance, for each client, was thus tabulated and subjected to statistical analysis

RESULTS AND DISCUSSIONS

The study was carried out with the aim of assessing the usefulness of transcranial CROS hearing aid in clients with unilateral hearing loss. Eleven clients (7 males and 4 females) were evaluated in different conditions to accomplish the assessment.

Results are discussed under the following headings:

I. Speech recognition score (SRS) in the presence of noise.

A. Unaided and aided SRS in the direct listening condition

B. Unaided and aided SRS in the indirect listening condition.

II. Horizontal plane localization

III. Performance through telephone.

I. Speech recognition score (SRS) in the presence of noise

A. Unaided and aided SRS in the direct listening condition:

Table I: Mean, Range, S.D., t values, between the unaided and aided, in the direct listening condition.

	Mean SRS (*)	Range	S.D.	t	Level of significance
Unaided N=ll	49.81 (98.00)	48-50 (96-100)	0.57	1.11	Not significant
Aided N=ll	50 (100)	50 (100)	0		

Note: * Values within brackets indicate percentage scores.

Table 1 shows the mean, range, standard deviation and t values for SRS, in unaided and aided conditions, for the direct listening. It is evident from the Table 1 that there is no significant difference between unaided and aided condition even at 0.05 level. Almost all clients, but one, obtained the highest score in the direct listening unaided condition. So there is no chance for the aided condition (T-CROS worn) to further improve the score any more as the speech stimuli were presented from better ear side and the noise which was presented from the side of poorer ear did not interfere with the speech recognition scores. Whereas, studies by Mackeith and Coles (1971), in a similar listening condition, aided with CROS hearing aid, have shown severe degradation of SRS as noise picked up by mic from the side of poorer ear might have interfered with speech stimuli. Thus, clients with CROS hearing aid may require to switch-off the device in such adverse listening condition, where as, clients with transcranial CROS need not do so.

B. Unaided and aided SRS in indirect listening condition:

Table 2: *Mean, Range, S.D., t values indicating significance of difference for unaided and aided SRS in the indirect listening condition.*

	Mean SRS (*)	Range	S.D.	t	Level of significance
Unaided N=11	41.18 (82.36)	38.95 (76-90)	2.20	8.90	0.01 level
Aided N=11	48.73 (96.72)	47.50 (54-100)	2.09		

Note: * Values within brackets indicate percentage scores.

From the Table 2 it is evident that there is significant difference in SRS between aided and unaided conditions, at 0.01 level.

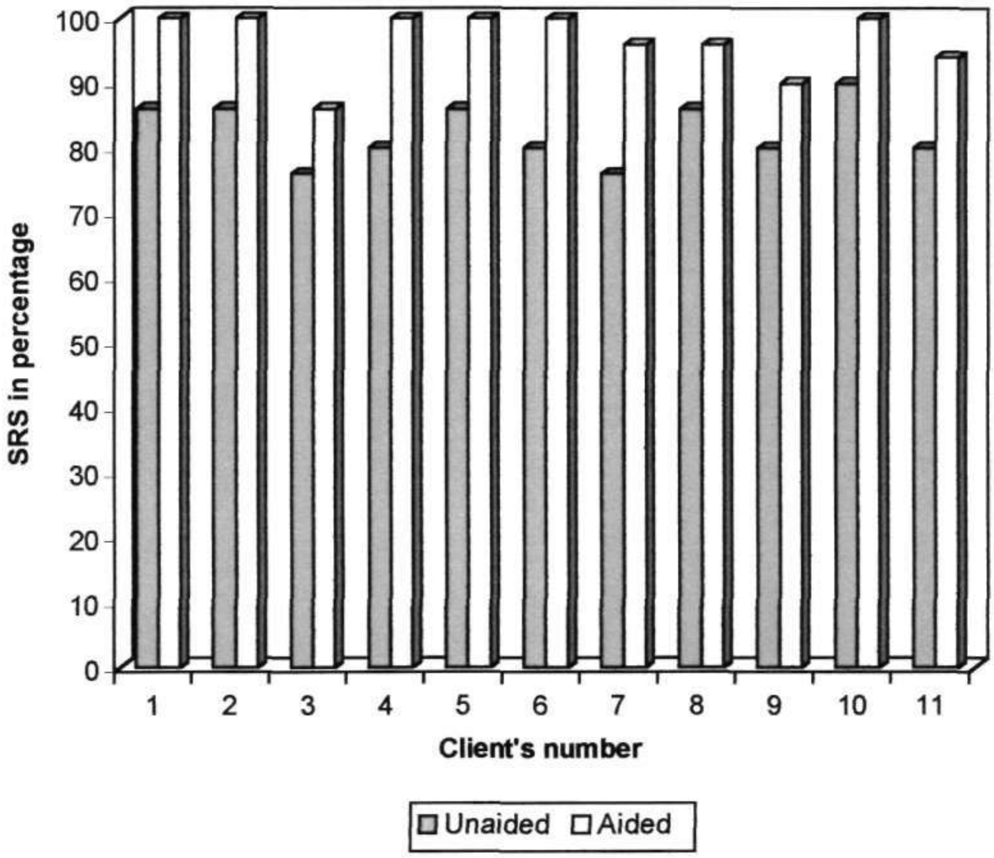


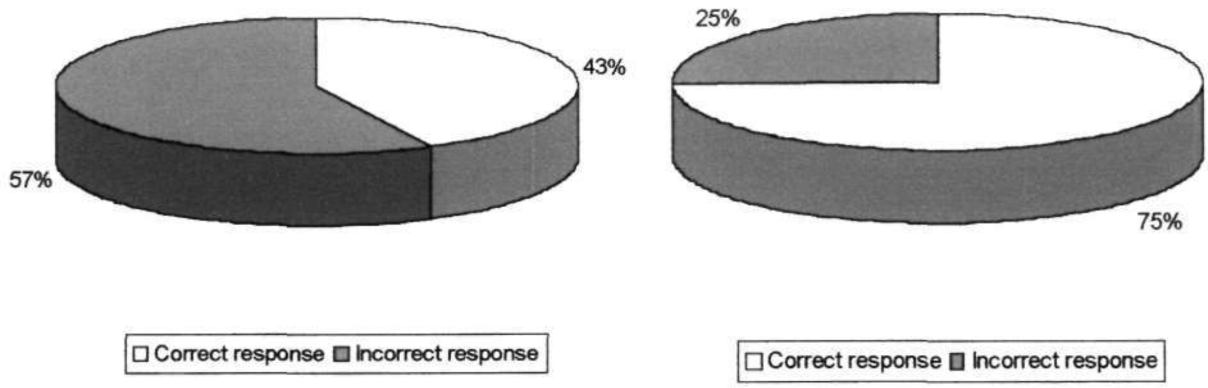
Fig 1. Unaided and aided SRS in the indirect listening condition for 11 clients.

From Table 2 and Figure 1, it can be observed that none of the clients achieved the highest score is unaided condition. Thus, it is clear that the T-CROS hearing aid in the indirect situation, i.e., when the speech is presented from the side of the bad ear, brought about a significantly higher mean SRS than the mean SRS in unaided condition. These results are almost comparable with the results reported by Mackeith and Coles (1971) where they had used conventional CROS and got significant improvement in indirect listening condition. These results also conform to the findings by Valente, Potts, Valente and Goebel (1995), where they have got better SRS with Transcranial CROS.

II. Horizontal plane localization:

Table 3: Mean, Range, S.D and t values between means for correct localization of sound source (out of 10) in unaided and aided conditions

	Mean SRS	Range	S.D.	t	Level of significance
Unaided N=11	4.27	1-7	2.09	4.12	0.01
Aided N=11	7.45	2-10	1.19		



UNAIDED AIDED

Fig 2: Average scores for localization of sound source, in unaided and aided conditions.

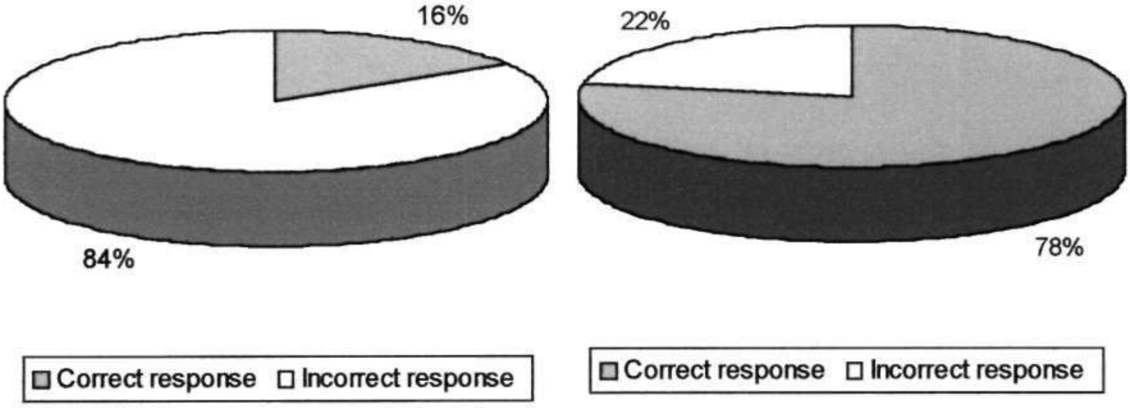
It is evident from the Fig. 2 that there is a definite improvement in localization in the aided condition (with T- CROS) and this was statistically significant at 0.01 significant level (Table 3), though there was variability among the subjects as the range of improvement in scores varied from 0 to 6. Chartrand (1991) has also reported in his single case study using transcranial CROS, that there is improvement in localization ability and further stated that, although the use of one cochlea in a transcranial fitting hardly represents the binaural fusion effect itself, it does help clients learn to recognize direction and proximity, because two separate routes of transmission are used (i.e., through the normal hearing ear and by conduction from the opposite air conduction amplified ear).

Introduction of a third speaker (in center), which was functionally disabled, did not rule out the chances of false response to a great extent as it was evident during the testing that seven of the eleven clients could not localize, all the time, for the speech noise presented from sides of better ear during unaided condition. Though the given task for localization was not that complex, the clients still made errors in correct localization of sound source. Thus, it is suggestive that the complex localization task e.g. keeping more numbers of sound sources at smaller angular difference from different directions might give more information.

III. Performance through telephone

Table 4: *Mean, Range, S.D., t value and significance of difference of mean in unaided and aided performance on telephone.*

	Mean SRS	Range	S.D.	t	Level of significance
Unaided N=11	0.81	0-4	1.26	5.42	0.01
Aided N=11	3.90	3-5	1.44		



UNAIDED AIDED

Fig. 3: Unaided and aided performance on telephone

The performance of the clients over telephone in poorer ear with and without transcranial CROS is depicted in Figure 3. Table 4 depicts that there is a significant improvement in performance at 0.01 level, over telephone, with transcranial CROS.

Most of the clients (seven of eleven) got a score of zero out of five (0/5) without transcranial CROS. However, with the use of transcranial CROS, almost all the clients got maximum possible score compared to unaided condition. It was observed during the testing that, the client could not give good response in noisy environment (2-3 people speaking around the client, during conversation on telephone). One possible reason for the degradation of performance in noisy environment could be that the environment noise heard by the normal ear of client could interfere with processing of speech signal received from the telephone in the poorer ear or it could be simply because of masking effect of environmental noise as also experienced by normal hearing person during conversation on telephone.

Thus, the use of transcranial CROS hearing aid during telephone conversation can be in terms of ease of listening and also useful for the client who was habituated to use phone in the poorer ear, before the hearing loss was acquired. Usually it is seen that most of people prefer receiving phone on left ear using left hand so that he /she can spare right hand (right handed person) to write down the message, if any. So if a client who is having hearing impairment in left ear, still can use left ear aided with transcranial CROS, to receive phone and can spare right hand for other work (e.g. writing), otherwise, the better ear is always left open/unoccluded, so that client can use during telephone conversations.

SUMMARY AND CONCLUSION

In the present study an effort was made to find out the usefulness of Transcranial CROS hearing aid in clients with unilateral sensorineural hearing loss. In literature, CROS amplification and its variations have been advocated for such clients, but there is a dearth of studies to support usefulness of Transcranial CROS hearing aid.

Eleven clients aged between 13-55 years fulfilling the criteria of unilateral unaidable sensorineural hearing loss were included in this study. Best suitable hearing aid was selected by using insertion gain measurements following a protocol where transcranial thresholds (TCTs) served as thresholds for creating target gain. After selection of hearing aid its usefulness was investigated by evaluating the speech recognition score (SRS) in noise, localization in horizontal plane and performance over telephone among the clients.

Results obtained were as follows:

> There was no significant difference in SRS in the direct listening condition.

> Statistically significance difference (at 0.01 level) was observed for all other conditions i.e., SRS in the indirect condition, horizontal localization and also on telephone performance improved with T-CROS.

This study supports the previous studies carried out by Chartrand (1991) and Valente (1995) where they had also found improvement in SRS in presence of noise as well as improved localization.

Suggestions for future research

- SRS in presence of noise could be obtained at different S/N ratios.
- Localization could be investigated under more complex task, keeping the sound source in different directions to simulate natural condition
- All these investigations could be done taking more number of subjects in different age group.

REFERENCES

Aufricht, H. (1972). A follow-up study of the CROS hearing aid. *Journal of Speech and Hearing Disorders, 37,* 113-117.26

Bergman, N. (1957). Binaural hearing. *Archives of Otolaryngology, 66*, 572-578.

Bess, F.H. & Tharpe A.M. (1986). An introduction to unilateral sensorineural hearing loss in children. *Ear and hearing, 7,* 3-13.

Bocca, E. (1955). Binaural hearing : Another approach. *Laryngoscope, 65,* 572-578.

Brookhouser, P.E., Worthington, D.W. & Kelly W.J. (1991). Unilateral hearing loss in Children. *Laryngoscope, 101,* 1264-1272.

Chartrand, M.S. (1991). Transcranial or internal CROS fittings: Evaluation and validation protocol. *Hearing Journal, 44,* 24-28.

Cherry, E.C. (1961). *On human communication* (3rd ed.). London: The MIT Press.

Cherry, E.C. & Sayers, B.M. (1956). Human cross-correlator: A technique for measuring certain parameters of speech perception. *Journal of the Acoustical Society of America, 28,* 889-95.

Culbertson, J.L.& Gilbert, J.E. (1986). Children with unilateral sensorineural hearing loss. Cognitive, academic and social development. *Ear and Hearing, 7,* 43-51.

Everberg G (1960). Etiology of unilateral total deafness. *Annals of Otology, Rhinology and laryngology, 69,* 711-713.

Fowler, E.P. (1960). Bilateral hearing aids for monaural total deafness. A suggestion for better hearing. *Archives of Otolaryngology, 72,* 57-58.

Giolas, T.G. & Wark, D.J. (1967). Communication problems associated with unilateral hearing loss. *Journal of Speech and Hearing Disorder, 32 (4),* 336-342.

Groen, J.J. and Hellema, A.CM. (1960). Binaural speech audiometry. *Acta otolaryngology, 52,* 397-414.

Harford, E. and Dodds, E. (1966). The clinical application of CROS. A hearing aid for unilateral hearing loss. *Archives of Otolaryngology, 83,* 455-64.

Harford, E. and Musket, C.N. (1964). Binaural hearing with one hearing aid. *Journal of Speech and Hearing Disorders, 29,*133-46.

Harford, E. and Barry, J. (1965). A rehabilitative approach to the problem of unilateral hearing impairment: Contralateral routing of signals (CROS). *Journal of Speech and Hearing Disorders,* 30, 133-146.

Katz, J. (2002). *Hand Book of Clinical Audiology,(*5[xh] ed.). Baltimore, Mary Land, U.S.A.

Koenig, W (1950). Subjective effects in binaural hearing. *Journal of the Acoustical Society of America, 22,* 61-62.

Lotterman, S.H., Kasten, R.N. and Revoile, S.G. (1967). Acoustic gain and threshold improvement in hearing aid selection. *Journal of Speech and Hearing Research, 10,* 859-868.

MacKeith, N.W. and Coles, R.R.A. (1971). Binaural advantages in hearing of speech.. *Journal of Laryngology and Otology, 85,* 213-232.

Malles, I. (1963). Hearing aid effect in unilateral conductive deafness. *Archives of Otolaryngology, 77,* 406-08.

Markides, A. (1977). Advantages of binaural over monaural hearing, in Markides A (ed): *Binaural hearing aids.* London: Academic Press.Ltd.

Martin, F.N. & Clark,G.J. (2002). (Ed.). *Introduction to Audiology.* (6[th] ed). Boston: Allyn and Bacon

McSpaden J.B., McSpaden C.H. (1989). A method for evaluating the efficacy and effectiveness of transcranial CROS fittings, *.Audecibel,* 38, 10-14.

McSpaden JB (1990). One approach to a unilateral "dead" ear. *Audecibel, 39,* 32-37.

Miller A.L. (1989). An alternative approach to CROS and Bi-CROS hearing aids: An internal CROS. *Audecibel, 99,* 20-21.

Miller, A.L. (1965). A case of severe unilateral hearing loss helped by a hearing aid. *Journal of Speech and Hearing Disorders, 30,* 186-187.

Pollack, I. and Pickett, J.M. (1958). Stereophonic listening and speech intelligibility against voice babble. *Journal of the Acoustical Society of America, 30,* 131-133.

Pruszewicz, A., Obrebowski, A., Woznica, B., Sekula, A., Swidzinski, P., and Karlik, M. (2001). Audiological assessment of unilateral deafness, *Scandinavian Audiology, Supp. 52, 30*, 32-35.

Punch JF (1988). CROS revised. *A Journal of The American Speech and Hearing Association, 30,* 35-37.

Sullivan R.F. (1988). Transcranial ITE CROS. *Hearing Instruments, 39,* 11-12, 54.

Tarkkanen J. and Aho J. (1966). Unilateral deafness in children. *Journal of Otolaryngology, 61*, 270-278.

Tillman, T.W., Kasten, R.N. and Hornier, J.S. (1963). Effect of head shadow on reception of speech. *A Journal of The American Speech and Hearing Association, 5,* 778-79.

The Person With Disability Act (1995). *Ministry of Law, Justice and Company Affair,* New Delhi.

Tonning, F.M. (1971). Directional audiometry II. The influence of azimuth on the perception of speech. *Acta Otolaryngologica. 72*, 352-57.

Valente, M. (1995). Fitting option for unilateral hearing loss. *Hearing Journal,* 48,10,45-48.

Valente M, Potts L, Valente M, Goebel J (1995). Wireless CROS versus transcranial CROS far unilateral hearing loss. *American Journal of Audiology, 4,452-*458.

Valente M., Valent M., Meister M., Macauley K. and Vass W. (1994). Selecting and verifying hearing loss. In Valente M.(ed), *Strategies for selecting and verifying hearing aid fittings* (pp. 228-298). New York: Thieme Medical Publishers, Inc.

Vandana, S. (1998). *Speech Identification test for Kannada Speaking Children,* An unpublished Independent Project submitted to university of Mysore, Mysore.

Weber B, Roush J, and McElveen J (1992). Application of an implantable bone conduction hearing device to patients with unilateral sensorineural hearing loss. *Laryngoscope,* 702,538-542.

Wullstein, H.L. and Wigand, M.E. (1962). A hearing aid for single ear deafness and its requirements. *Acta Otolaryngologica. 54,* 136-42.