SPEECH PERCEPTION THROUGH TACTILE MODE - A REVIEW (1900-1991)

Reg.No.M91lO

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1992

Dedication

My revered parents

and my beloved brother

AND

To those rehabilitators who has spent their lives in listening patiently to the silence of the deaf and modifying their silent world into a world echoing with melody.

CERTIFICATE

This is to certify that the Independent Project entitled: SPEECH PERCEPTION THROUGH TACTILE MODE - A REVIEW (1980-1991) is the bonafide work in part fulfilment for M.Sc., in Speech and Hearing of the student with Reg.No.M9110 .

Director

Mysore
1992

All India Institute of
Speech and Hearing, Mysore

CERTIFICATE

This is to certify that the Independent Project entitled: SPEECH PERCEPTION THROUGH TACTILE MODE - A REVIEW (1990-1991) has been prepared under my supervision and guidance.

Mysore
1992

Dr.(Miss)S.Nikam,
GUIDE

DECLARATION

This Independent Project entitled: Speech Perception through Tactile Mode - A Review (1980-1991) is the result of my own study undertaken under the guidance of Dr.(Miss) S.Nikam, Prof, and Head of the 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.

Mysore.
1992. Reg.No.M911O.

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To staff members of the AIISH Library, especially Mr.Ramesh Babu, for providing adequate references for the project.

To my parents .....
Far away from home
I realize their eternal presence forever
Who made my life, a perpetual festival of joy
And showed me the DESTINY
The splendour of my small achievements
And all my life ,...
I offer them with joy.

To my dearest brother, E-Appee Peeba for lighting the lamp of encouragement in my darkened heart and making my spirit to aim higher.

Friendship needs no words -it is solitude delivered from the anguish of lonliness.

For the heartaches, tears and joy, I thank you for being a good friend, Dear Nirmal.

To my Guruji, Ms.N.Jyothi, for providing me an intellectual tonic throughout the years of my studies and encouraging me to wade through the deepest waters of knowledge.

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contd...

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For her excellent and elegant typing, a spontaneous overflow of heartfelt thanks to Rajalakshmi Akka without whom my project would not have acquired the look of a PROJECT itself.

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INTRODUCTION

"Life first acquires depth through hearing". Deafness is a very serious kind of disability. In free nature, a blind animal can exist as is proved by the mole, who is blind and by the kiwi who is nearly blind, but shall we look for the deaf vertebrates, who are not capable of living? As it is very understandable that deaf animals cannot live in this world. The organ of hearing is pre-eminently the organ of warming. This sense organ never sleeps, it is always vigilant and even during sleep, it is still active. In the silence of deaf, no vital space is present, no feeling of freedom. His silence is oppression In itself, in contrast to the silence valued by those with normal hearing, who experience a widening of their vital space in their silence. Let the silent world of deaf come to an end and let*s help them conquer the hearing world.

The sensory apparatus of hearing is an indispensable tool for hearing and for the development of speech and language. It' s functions are coordinated with other sensory modalities like vision, touch, taste and smell, the former two, being the most important. Those individuals who have been deprived of their sense of hearing might have to depend on the visual and tactile sense of communication. The severe and profound loss individuals with poorer speech discrimination

do not benefit only through the auditory mode. They may also have to depend on speech reading information received through the visual and tactile senses.

Sensory capability is the capacity of the organism to exhibit relatively simple behavioral or physiological responses to a set of simple and well controlled stimulus conditions.

Communication through the skin offers possibilities for adding to the ways of receiving information because of the ability to perceive through skin, a variety of patterns of pressure and vibration.

"Speech perception" refers to the decoding of speech stimuli; based on the acoustic and other cues. Speech Perception processes in human beings is still an unsolved puzzle. Speech perception may take place through either auditory, visual or tactile mode.

Tactile sensation may be elicited by direct electrical stimulation of the skin. When a vibrotactile stimulus is presented to the skin, quickly adapting mechanoreceptors are stimulated. The primary afferent fibres transmit the information from the mechanoreceptors to the dorsal horn of the spinal cord, where they ascend ipsllaterally in the dorsal column and terminate in the nuclei at the level of the medulla

in the brainstem. At that point, the fibres decussate and combine up the medial leminiscus to the thalamus.

From the thalamus, the vibrotactile information ascends to the somatoaensory area of the cortex. Since the cues utilized by deaf individual for speech reception are not necessarily isomorphic with those, used by the normal hearing population, the ultimate goal of a tactile communication system is to extract relevant acoustic speech information from the speech signal and to transpose it to the individual in a tactile mode as a means of supplementing or replacing the auditory reception of speech. Tactile stimulation on the skin has been accomplished mainly in two ways - (1) Using vibrotactile stimulation where vibrations are imposed on the skin and (2) Electrocutaneous stimulation, where electric current is used to stimulate the skin surface. Types of tactile devices are separated into single Channel and multi-channel aids. The purpose of a single chann 1 is to carry the rhythm of the speaker's voice in order to develop attentiveness to the speaker's face and facilitate the use of visual cues. Multichannel devices are made up of individual vibrators that are perceived separately. Continuous multi-channel devices differ from discrete in that there are more vibrators, which are placed close together.

The purpose of this review is to highlight studies on speech perception through tactile devices. This study also

PAPERS ON "SPEECH PERCEPTION THROUGH TACTILE MODE - A REVIEW"

(1980-1991)

Spens K.E. (1980); 'Tactile Speech Communication aids for the deaf -'A comparison!, Speech Transmission Laboratory quarterly Progress and Status Report, No.4, Pg. 23r39.

This investigation was designed as a comparative study between some of the different speech conveying tactile systems for the deaf, described In recent literature. The systems used in this study are (1) Single vibrator system applied on the fingers. (2) Single vibrator system stimulating other body loci. (3) Stimulator arrays (spatial dimensions). (4) Matrix mapped on the fingers (two spatial dimension). (5) Matrix system stimulating the abdomen (two spatial dimensions).

The correctly conveyed tactile information was measured, using the same method, vocabulary and subject for all the systems used. They included Swedish numerals in the vocabulary, which had small variations in timing, level and pronounclation. Only one subject was tested, who was unfamiliar with different types of tactile systems, except for optacon. One control subject was however included, who was blind, but a well-trained optacon reader. No auditory or visual information was presented. Masking was done under necessary conditions.

The results are possible to rank order by two factors. The most important factor seems to be the amount of processing

of speech information in order to match the tactile stimulation to the characteristics of the skin. The second factor is the place of stimulation.

All the systems conveyed information on a phonetic level about the spoken words. The correct responses ranged from 50% to 70% in all the systems. However, the conveyed information included three main types of confusion matrices:

(1) Spectral changes, which involve large intensity as in initial and final part of a word and also in stops.
(2) Large spectral changes with minor intensity changes, such as changes from fricatives to vowels.
(3) Small spectral changes, like those from vowels to vowel like consonants.

The more the processing of the speech signal, the better the results. It should be noted that the results must be regarded as indications only, since for practical reasons, the vocabulary, the number of subjects and the training time had to be limited by the author. Actual learning curve could not be obtained in this study, because of the subject's inability to perceive information, pertaining to small spectral and temporal changes. The subject's performance might have improved if longer training periods were provided. As only one experimental subject was used in this study, there might have seen some transfer bedause of earlier experience and even some transfer between different tests is also possible. The

author justifies by stating that the transfer between the tests does affect the Initial results, but not the asymptotic level of performance. Even if the complexity of the display system is increased beyond that of an array, performance does not improve significantly. So, it may well be that, more optimal strategies, both in extracting the information from the speech signal and in presenting the information to the skin, must be found, before it is even possible to benefit from the potentially higher capacity of a matrix display. Furthermore, the study provides some useful conclusions, regarding the capacity of tactile systems in conveying information:

1) Choice of stimulation area. In this study, fingers were found to be the best choice of placement.
2) Amount of processing of speech signal including the number of spatial dimensions in the tactile display.
3) The information carried by large spectral changes are easier to learn.
4) There is no significant difference in performance which can be attributed to vibrotactile or electrotactile stimulation.

The study does not attempt to make an absolute evaluation of the tactile aids tested, but rather to make a relative comparision of the tactile information and conveying capacity of the aids.

Stroker, R.G., and Lape, W.N. (1980); Analysis of some non-auditory aspects of the speech of hearing-impaired children The Volta Review, Vol.82, Pg. 137-148.

The authors studied speech intelligibility in 42 children, 4-19 years of age, enrolled in a residential school. The factors considered under speech intelligibility included breath control, suprasegmental perception and production and lipreading. Hearing aid usage and tactile perception were found to be unrelated to speech intelligibility in the subjects studied. It is known that the deaf perceive low frequency acoustic stimuli through vibrotactile mode. Although, small frequency changes cannot be detected through the tactile mode, most individuals can Identify time and Intensity differences in speech. The authors actually wanted to find out whether the skill at tactile interpretation of the time-intensity (waveform) envelope might transfer to skill in speech production. But they found negative correlation between tactile perception and speech intelligibility of the speaker.Tactile perception of speech is an area of much current interest and It would be premature to suggest that tactile perception is not related to speech intelligibility.

Oiler, D.K., Payne, S.L., and Gavin, W.J. (1960): Tactual Speech perception by minimally trained deaf subjects. JSHR, Vol.23, Pg.769-778.

The authors highlight that deaf perceivers may also be able to discriminate some hard-to-lipread word pairs after a short training period. If so, tactual vocoders could offer almost immediate benefits to the deaf people. The transmission of certain speech information not available through the traditional method of lipreading and the provision of a useful feedback system for imitation in speech production training. This study investigated the benefits of employing tactual vocoders in speech perception for the deaf persons after a brief training period.

The basic questions. investigated in this present study were -

1. Can young deaf people learn to discriminate hard-to-lipread word pairs after a brief period?

2. Can this learning be shown to apply to perception of both male and female voices?

3. Can deaf perceivers be shown to respond to features of tactual patterns (for eg. spatial length) in a manner that parallels responses of normal hearing individuals?

Eight deaf adolescents assisted as subjects in this experiment whose hearing loss was profound. A tactual vocoder was used and each subject was required to discriminate between the members of hard to lip-read word pairs, based on tactual information. The stimuli employed were pairs of words contrasting in manner of articulation, but not in visible place of articulation.

The results convey that, with a brief training period of one hour, the subjects can attain a high level of perceptual performance with a tactual speech system in discrimination of certain hard to lipread word pairs pronounced by both a male and a female speaker. Some speech sounds , previously indistinguishable, can immediately be available for speech comprehension through the tactual vocoder; and other speech sounds will be recognized with further training. It was found that word patterns that result in stimulation across a greater area of skin tend to be more discriminate than word patterns which stimulate only small areas of the skin. Statistical procedures used in this study were appropriate. It is reasonable to expect from this study that the speech perception aid afforded by the tactual vocoder may be of substantial general importance, even with a limited training experience. The progress made by the subjects is worth noting, even when systematic speech production training

was not given. The testing of tactual pattern perception models should include both natural and synthetic speech stimuli, which was not present in this study. However, the study predicts substantial positive effects on speech production skills when perception becomes well-established in case of deaf subjects.

Plant, G.L. (1982): Tactile perception by the profoundly deaf: speech and environmental sounds. B.J.A. Vol.16, Pg. 233-245.

This study was carried out with the purpose of evaluating the performance of experienced aid users on tasks falling into four broad categories..

1. Lipreading with and without vibrotactile supplement,
2. Detection of segmental features,
3. Discrimination of prosodic features,
4. Discrimination of common environmental sounds.

Pour subjects were fitted with single - channel vibrotactile aids and were provided with training using those instrument.

Results indicated that the vibrotactile aid provided useful information as to speech and non-speech stimuli, with the subjects, performing best on those tasks, where time or intensity cues provided sufficient information to enable identification.

Table - Percentage of information transmitted for the consonantal features, nasality, manner, voicing and place in the unvoiced (lipreading alone) and aided (lipreading plus tactual information) condition.

Feature	Unaided	Aided
Nasality	26.69	44.58
Manner	65.26	72.38
Voicing	10.42	27.15
Place	89.95	90.94

The above table indicates that recognition of features of voicing, nasality and manner were enhanced by vibrotactile aid because of timeand intensity information presented by the aid. Though durational and intensity cues are available to the subjects, they had great difficulty in identifying stress on the latter words of the sentence. Analysis of the test results revealed that the subjects performed best in those tasks for which time and intensity cues provided sufficient Information to enable identification. Tasks such as identification of consonants, word discrimination etc. were very difficult where as the identification of word and sentence patterns, syllable number in sentences, etc. were comparatively easier. Until some sophisticated and effective vibrotactile aids are developed, single channel vibrotactile aids should be seen as a simple interim means of providing assistance to the profoundly deaf.

Oliver, P. et al. (1982): A prosthetic device utilizing vibrotactile perception of profoundly deaf children. British Journal of Audiology, Vol.16, Pg.277-279.

Vibrotactile perceptual mode affords adequate information about duration and intensity and have rhythm and accent, but is severely limited, as far as frequency is concerned, the upper limit, being around 1000 Hz. Differential perception of frequency is rather crude, but nevertheless sufficient to provide information about large variation in fundamentals of speech.

In order to afford a means for deaf children, to benefit from vibrotactile perception in free-field condition, a vibratory stimulation prostheticdevice (VSPD) as described by Boorsma in 1975, has been utilized for the last your years. This consisted of a small vibrator clipped to an earmold and connected to a standard body worn hearing aid. VSPD stimulates speech production when it is worn continuously. It also facilitates language acquisition, through a better contact with educators and with acoustic environment. It is an efficient means of voice-pitch correction. It is of greater use, if subjects already know the verbo-tonal method. The number and selection of subjects taken have not been specified.

Clements, M.A., Braida, L.D., and Durlach, N.I. (1982): Tactile
3 Communication of speech : Comparison of two spectral displays in a vowel discrimination task. JASA, Vol.72, Pg.1131-1136.

The statistical hypothesis stated in this study is as follows:

"Vowel discrimination may be slightly better on the Time Swept Display than on Frequency Amplitude Display".

Vowel discrimination experiments were performed, comparing two tactile Optacon based spectral displays, a frequency amplitude (FA) display and a time swept (TS) display. One set of materials were synthetic vowels and the other set was consonants (/b/ and / t /) .

The score obtained on vowels were better than the consonants. The score obtained with the TS display was slightly better than with the FA display. The features, best differentiated in TS display were tenseness, followed by the features high and low, then by round and back and finally by retroflexion: All other features were not accounted for, in this study. The probable reason why time swept display is better has been highlighted. The TS display attempts to simulate the perception of movement and therefore, more closely related to the natural use of the tactile sense and to provide memory in display.

Offhand, one might aspect performance with the TS display relative to that with the PA display to be better for speech segments that have time - varying spectra and worse for segments that are steady-state. Thus, to the extent that vowels, taken up in this study are steady state, the materials should favour the PA display. It is not explained why the scores for synthetic materials were higher than natural materials. No clear cut correlation was however found between duration performance and physical parameters of the stimuli. Statistical procedures used, seems to be adequate.

Reed C.H., Durlach, N. I., Bralda, L.D., and Schultz, M.C. (1982): Analytic study of the tadoma method :Identification of consonants and vowels by an experienced Tadoma user, JSHR, Vol.25, 108-116.

The aim in this study was to probe into the perception of speech stimuli by an experienced Tadoma user. The stimuli were sets of nonsense syllables and diphthongs. A total of 19 features were incorporated in the study. Confusion matrices were constructed and sequential information analysis (SINFA) was done. In this technique, the contribution of various phonological and articulatory features are assessed sequentially and independently in terms of information transfer, taking into account. The redundancies that existed for the

various features. For a set of 24 consonants in CV syllables, performance averaged 55%. For a set of 15 vowels and diphthongs in CVC syllables, performance averaged 56%. Confusion matrices were analyzed for performance on a set of articulatory/phonological features. The results of the feature analysis for consonants indicated that the features, voicing, lip sounding, frication and place were well perceived: for vowels, the features, lip mounding , tenseness and vertical lip separation were well perceived. The results are qualitatively consistent with those of the discrimination tests obtained by other authors for normal subjects.

This study has got a loophole in these sense that only one subject has been included. It could have been done, taking more subjects. This experiment can also be performed with nonsense syllable identification tasks on normal subjects with simulated deafness and blindness and with only modest amount of training. Experiments can also be performed by imposing limitations on hand position (eg. thumb removed from the lips, fingers removed from the cheek, etc.).

Snyder, J.C., Clements, M.A., Reed, C.M., Durlach, N.I., Braida, L.D. (1982): Tactile communication of speech: Comparison of Tadoma and frequency amplitude spectral display in a Consonant discrimination task, JASA, 71, 5, 1249-1255.

This study aims at comparing Tadoma and an optacon based frequency amplitude, spectral display. The authors conducted experiments on consonant discrimination.

Consonants were presented to the subjects through an Optacon based frequency amplitude spectral display and Tadoma method. The results of these experiments which employed common subjects and procedures, indicate that Tadoma is substantially superior for discriminating consonant pairs that differ in voicing and place of articulation, but not for discriminating pairs that differ in manner of articulation. The overall superiority of Tadoma revealed in these consonant discrimination experiments should not be generalized to spectral displays, as such. The results obtained with Tadoma was found to be superior, as it is directly tied to the articulation process or because, more generally, it is a much richer display (including many sensory qualities).

The superior results with Tadoma may also be due to greater amount of training. Specific spatial displays is substantially inferior to Tadoma with respect to the discrimination of consonants, particularly with respect to voicing and place contrasts. From the above study, it cannot be concluded that this type of inferiory holds for all types of speech materials.

This study cannot be generalized to other spectral displays since they be superior to the Optacon based display which is considered in this study.

Patti, S., and Suzan, A.H. (1983): The use of vibrotactile aids with preschool hearing-impaired children: Case studies. The Volta Review, Vol.85, Pg. 14-26.

This study aimed to find out the children's response to the use of vibrotactile input. The purpose of vibrotactile stimulation is to provide additional sensory input to the information, the hearing impaired child is able to receive auditorily and visually. The authors had chosen three students, for a 6 month period of structured observation. The subjects had bilateral, profound, sensori-neural hearing loss. All the three were 4-3 years old. Wearable vibrotactile aids were used. The Siemens Fonator was used primarily to develop a feedback system for speech production. Nonsegmental aspects of speech and vowels were introduced first, for discrimination, then imitation and finally production. Presentation was often tactile and auditory only, as lipreadlng cues were frequently not frequently. Materials included pictures cue cards for duration, pitch, rhythm patterns and Intensity; puppets; manipulative objects; and motor responses. A subjective evaluation of a number of factors, related to vibrotactile input was conducted through the use of parent and teacher questionnaires. In looking at the advantages and disadvantages of the daily use of these aids, all parents and teachers felt the children's Increased awareness of sound, was the main advantage, along with better

awareness of the non-segmental aspects of speech. The disadvantages of these aids, centered on the durability of the aids, feedback problems the wearing arrangements and usage of these aids in a noisy environment, where the influx of sound makes the unit vibrate continuously. The authors concluded that the children' s response to the use of vibrotactlle input has far exceeded expectations. Since consonants contain more feature information than vowels, it is anticipated that the use of vibrotactlle stimulation will be of even greater benefit to these children in the future. The progress of the children from discrimination to imitation to spontaneous production would seem to indicate that these children had developed an effective feedback system. Only three subjects were taken up in this study. Actually, the author could have done a large sample study to achieve more external validity.

Adele, P., and Moise H. and Goldstein, J. (1983): Development of lexical comprehension in a profoundly deaf child, using a wearable, vibrotactlle communication aid, LSHSS, Vol.14, No.3, Pg. 138-49.

The authors did a longitudinal study of a profoundly deaf young child, with the aid of a vibrotactile communication device. The training started when the child was 33 months

old and it continued, till she was 44 months. After 10 months of training, with the device, and traditional aural/ oral teaching techniques, the child acquired an understanding of 469 words. The subject's pattern of lexical comprehension was like that of younger hearing subjects.

This study highlighted that the rapid rate of lexical acquisition appears to have been strongly Influenced by the use of vibrotactile communication aid. However, this study could have used more than profoundly deaf children and should have used control groups consisting of normal hearing children and profoundly deaf children, Who were not trained with the vibrotactile device.

Plant, G. (1983): The use of vibrotactile aids with profoundly deaf children, STL-QPSR, No.l,Pg. 36-51.

The aim of this study was to evaluate children's ability to identify a number of prosodic features at both the word and sentence level, plus the ability to discriminate selected segmental features.

Three profoundly deaf children (7-11 years) were fitted with vibrotactile aids and were provided training sessions over periods, ranging from 18 months to 3 years. Prosodic features, evaluated were syllable number and type in words and syllable patterns in sentences. Segmental features examined

were vowel length, final consonant voicing, presence or absence of initial or final /s/ and presence or absence of initial or final /a/. In almost all cases, the scores were well above chance level of performance, indicating that the aids provide/useful information to both segmental and supragegmental features. The aids enable the children to recognize both word and sentence patterns. Performance at the segmental level showed/that the aids provided information which can be used to assist in both speech production and perception.

The tasks involving the detection of fricatives highlighted the value of the aid in providing information, regarding the fricatives. However, the disadvantages are that the aid can be confined only to the classroom activities and also the output transducers are hand-held which hampered the manual communication system.

Plant, G., and Spens, K.E. (1983): A tactual hearing aid for the deaf. STL-OPSR, No.l, Pg. 52-56 Haskins Laboratory Reports.

The authors here describe the development of a new wearable hearing aid for the profoundly deaf and initial results, obtained with a group of deaf subjects. The aid

transforms the sounds of speech and the environment into tactile patterns which are received by the skin. The aid looks like a conventional body worn hearing aid, which has a built in microphone and the circuit is designed to extract the intensity (loudness) variations of sound and convert them" into vibratory patterns. These patterns are felt via a small vibrator which is connected to the aid by a thin cord. The vibrator is designed to match the vibratory capacities of the skin, while using less power. The aid's potential lies in three main areas: (1) a) The awareness of sounds in the environment (b) The detection of warning signals in the environment (2) As a supplement to lipreading. (3) Provide information enabling the person to monitor his/her own voice. Fifteen deaf were taken up for the study to determine the effectiveness of the aid. The subjective evaluation consisted of a questionnaire which sought to obtain the deaf person's own perception of his/her handicap with and without the vlbrotactile aid for the areas; environmental sounds, lip-reading and voice monitoring. The higher the scores, the less the subject's own rating of his handicap. It was found that in the perception of environmental sounds, and in lipreading, the subjects feel that the aid provides positive benefits. For the monitoring of the subject's

own voice, however, it appears that there are no difference between the aided and unaided conditions.

Scores obtained on a subjective rating scale and in the aided and unaided condition.

	Aided	Unaided
Environmental sounds	30	8
Lipreadlng	50	31
Monitoring of own voice	13	12

The results also highlight the value of the vibratory signal as a supplement to lipreading even with minimally trained subjects. However, the study has restricted itself to a minimum number of parameters for evaluation of the aid, which could have been extended further.

Green, B.C., Craig, J.C., Wilson, A.M., Pisoni, D.B., and Rhodes, R.P. (1983): Vibrotactile identification of vowels. JASA, 73, Pg.1766-1788.

The present study explores the effectiveness of the Optacon transducer, using a number of different coding schemes. Initially, the amount of information contained in a two-dimensional spectral displaywas varied by changing the number of spectral channels, presented to the skin, while simultaneously, comparing two "modes" of presenting the information.

Later on, the size of the tactile pattern was manipulated, and finally, performance with the spectral display was compared to performance with a vocal tract display. A spectral display consisted of frequency versus intensity function and a vocal tract area function display consisted or vocal tract location by cross-sectional area. Both displays were presented to the finger tip via the tactile display of the optacon transducers.

Normal hearing subjects participated in this study. In the first experiments, the spectral display was effective for identifying vowels, where 24 spectral channels were presented to the skin. However, performance feel, when the number of channels were reduced. The effect of reducing the size of the display was greater, when the spectrum was represented as a solid histogram ("filled" patterns) than, when it was represented as a simple spectral contour ("unfilled" patterns). Spatial masking within the filled pattern was postulated as the cause for the decline in performance. Another experiment measured the utility of the spectral display when the syllables were produced by multiple speakers. The resulting increase in response confusions was primarily attributable to variations in the tactile patterns, caused by differences in vocal tract resonances, among the speakers. The final experiment found an area function display to be inferior to the spectral display

for identification of vowels. The results demonstrated that a two dimensional spectral display is worthy of further development as a basic vibrotactile display for speech.

A vocal tract display was found to be inferior to the spectral display. Inverting the representation of the vocal tract on the fingertip showed that the finger is not uniformly sensitive to patterns produced along it's length. In summary, these experiments indicated that a two-dimensional spectral display (with as few as eight channels) provides sufficient speech information for identification of vowels in CV syllables, and is therefore a good prospect for continued development.

Plant, G. and Risberg, A. (1963): The transmission of fundamental frequency variations Via a single channel vibrotactile aid. STL-QPSR. No.2-3, Pg. 61-84.

This paper reports preliminary results obtained with a single channel vibrotactile aid, designed to transmit fundamental frequency information.

A series of 4 experiments were carried out to evaluate a single channel vibrotactile aid which extracts a speaker's fundamental frequency and presents it in a range, where the skin is maximally sensitive to frequency change. The aid's

ability to convey emphatic stress in sentences and word syllable number and type was tested, using both English and Swedish materials.

The first experiment was aimed at assessing the ability of untrained observers to detect the stressed word in 3-4, word English sentences. The results indicated that the aid provides useful information as to emphatic stress in English sentences.

The second experiment, was aimed at evaluating the aid's ability to transmit word syllable number and type and the teat items consisted of English monosyllable, trochees, spondees and trisyllables.

Results indicated that the scores were above chance level performance and the subject's errors occurred in a relatively systematic fashion. However, it was a difficult task for both the groups. The

The experiment III used Swedish rhyme test materials and identification of syllabic contrasts were tested. Results indicated that better the familiarity, better the word syllable identification.

The experiment IV Involved the perception of emphatic stress in Swedish sentences. It was found that primary cue

to emphatic stress was frequency change with relatively weak intensity, and durational cues.

The overall results indicated that the aid transmits such Informations at a high level, although it appears that extensive training would be needed with some tasks before optimal performance is attained.

It can be speculated that the subject's performance would improve if the speaker used a rate of articulation that is slower than normal. It can also be investigated whether the temporal resolution of the skin can be improved with training before deciding to introduce a speaking strategy Which leads to a decline in speech production. Further research needs to be done to determine, whether the signal provided by the aid is a useful supplement to assist in lipreading and speech production. Consideration also needs to be given to the provision of informations, other than fundamental frequency, which will serve to improve the signal already available.

Brooks, P.L.,and Frost, B.J. (1983): Evaluation of a tactile vocoder for word recognition, JASA, Vol.74, Pg.34-39.

The purpose of this study was to evaluate the usefulness of a tactile vocoder in a study that was designed to combine

many features considered by the authors. Some of these features were one-third octave filtering, a linear array using solenoids as the transducers and a carrier frequency for the solenoids of 100 Hz. Normal subjects were taken up in this study who learned to identify words through a tactile vocoder; with 16 filter channels and output of each filter was detected which was transmitted to a solenoid array placed on the subject's ventromedial forearm. Live voice was used as a stimuli. In 40-5 hours, the subject learned 70 words and 2nd subject learned 150 words in 55 hours. It was found that, words that were poorly identified initially, were identified more readily with Increased experience. Phonetic identification tests showed that the features of voicing, nasality and frication were reliably recognized, indicating that the tactile vocoder will be useful, providing information to component lipreading. Finally, subjects learned rapidly to generalize word-learning to unfamiliar readers. Words that had lower/higher probability of being identified correctly were similar across subjects. Both found some words easy to learn and other words more difficult to learn.

In this study, nasality appears to be transmitted very reliably, but identification of particular nasal sound was a more difficult task. Frication was also identified well, but errors for unvoiced fricatives /f/ and /o/ were due to the fact that this Information was not being transmitted through the system due to the amplitude of these fricatives.

It is difficult to compare the learning rates (in this study) with those found, using other communication systems, because methodologies, stimuli and subjects vary greatly. Evaluation of error patterns was done in this study, for future modification of the vocoder. To know the true limits of the system, the following steps can be taken up:

1. Identification of converted speech could have been studied.
2. One report could have been published on one prelingual deaf subject.
3. The device could have been made portable so that light might be thrown in realistic situations.
4. The device should be tested on young deaf children so that an advantage may be taken of the neural plasticity that exists in the human nervous system.

Sherrick, C.E. (1984): Basic and applied research on tactile aids for the deaf: Progress and prospects, JASA, Vol.75, Pg.1325-1342.

This report summarizes the consensus of a group of American investigators who analysed the capabilities of the touch and allied bodily senses for processing information.

that is normally handled by the sense of hearing. The authors briefly introduce the alternative methods for replacement of the sense of hearing, including the educational procedures of sign language and lipreading, the medical procedure of cochlear implants, and the sensory substitution procedures of visual or tactual displays* For the tactual displays, which are most commonly electronically activated, desirable objectives are given. Among these are a better understanding of the processing of capabilities of the skin, the form an efficient transducer may take, and what features of the speech stream may most profitably be extracted for processing and display to the sense of touch. Because, the technology for device design and production in this area is seriously retarded, a great amount of space is devoted to the precise specification of a transducer for the tactile display. A multichannel displays exist, and several of these may be morbable systems if their transducer elements can be kept small and use little energy. What is of current, even urgent, importance is the early and widespread deployment of a single-channel tactile aid to permit the general assessment of the effectiveness of simple sensory adjuvant for a deaf person who has lipreading skills.

There are a number of reasons for recommending what may seem to be a precipitous move to those who know that

our understanding of speech perception and of the processing capabilities of the skin, as well as of the technology of transducer structure, is unsatisfactory. First, some deaf persons can make use of even a simple aid. Second, the results of such a study should put tactile aids into a better position for comparison with the cochlear Implants, for which the subject population is growing rapidly. Third, research and development efforts on tactile aids have often ended in the laboratory, ie the threshold of field trials. Yet such trials are the very situations in which individuals will test the limits of their aids, and sometimes develop ingeniously uses for them or use them in unforeseen conditions. This kind of experience in applied research is difficult to get in any other way, but it is invaluable to developers, not only for design revisions of current versions of devices, but also for any future system to be tested. It provides an evaluation of system performance that cannot be realized in the laboratory.

Carl, E. Sherrich (1985): Touch as a communicative sense: An introduction. JA5A, Vol.77. Pg -218-219

Touch may substitute one of the major senses in a thought that, like the field of psychology/itself, has a long past, but a short history.

In the process of arriving at the final cochlear model. Von Bekesy set out stakes in much of what has unknown territory in the akin sensory system. Except for the fact that both hearing and touch responded to mechanical forms of energy, they do not seem to be very closely related in the human anatomy. The inner ear is an insular organ with an intricate geometric design that accepts a special flux of mechanical energy, performs a rapid preliminary analysis of it, then connects it to a nervous message. The skin is a diffuse system occupied by myriad entities other than mechanoreceptors and hence, serving many other functions, not the least of which is to keep the environment, where it belongs. At the receptor level, the skin is less sensitive than the ear by perhaps fourteen orders of magnitude. In part, they presume that this is to lessen the effects of the shocks the flesh is heir to, but the result is that it takes much more energy to inform the skin, a fact that transducer designers continue to lament. Another notable difference between ear and the skin is the nature of the message, normally imparted through them. The skin, except for it's role in prehension as the non-intellectual sense, better adapted to some emotional needs.

John, R.P. et al. (1985): Neural mechanism of scanned and stationery touch. JASA, Vol.77, Pg.220-224

The neural mechanism, subserving the sense of touch, set the limits for the acquisition of information, regarding the spatial and temporal characteristics of stimuli. impinging on the skin surface. The results of the three different experiments imply that the skin pad can resolve the elements of a stimulus separated by 0.9 mm, when the stimulus is applied to the skin, held stationary. The resolution limit is only slightly improved (to about 0.7 mm) when the movement between the stimulus and skin is allowed. Single unit recordings from 3 classes of primary mechanoreceptive afferents in the anaesthesized monkeys show that only one class, the slowly adapting afferents, resolve spatial detail of stationary stimuli (eg. Braille dot patterns) more effectively than do the other two classes. However, these observations do not explain the extra ordinary capacity of the finger pad skin for discriminating between the textures. Neurophyslological evidence suggests that information about such textures (le surfaces with spatial details below the resolution limit), may be conveyed by a code, based on the relative engagement of the three receptor populations.

Frank, A.G. (1985): The mutability of time and apace on the Skin, JASA, Vol.77, Pg.233-237.

Radial shifts in perceived spatial relations can occur through the operation of the principle of sensory saltation. In the realm of cutaneous sensation, where it was first encountered and also in some auditory and visual situations, any brief stimulus preceding a 2nd one by no more than about 300 msec, will show apparent spatial displacement from it's veridical position. The degree of deviation is determined primarily by temporal relations between the two stimuli, but secondarily, by intensive ones as well. Limitations of the operation of the saltatory effect on the skihave been of such measurement, taken together with consideration of some aspects of the known neural seat of phenomenon.

James, C.Craig (1985); Tactile pattern perception and it' s perturbations. JASA, Vol.77 Pg-238-246

One of the problems encountered in conveying information to the skin by means by vibratory patterns is that presenting patterns, such as letters of the alphabet, in close spatial and temporal proxinity, may result in considerable masking. Backward masking is found to be more effective than forward masking. Masking may be reduced by increasing the temporal and spatial separation between

patterns, however other problems may arise, when such separations are made. Increasing spatial separation between patterns may lead to problems in combining the patterns from specially distinct sites on the skin. This difficulty may be due to problems in attending several sites of stimulation simultaneously. Temporally adjacent patterns produce masking; a subject's ability to identify a tactile pattern is reduced or interfered with by the presentation of other patterns. This article generally focuses on the temporal and spatial manipulation that might reduce masking and are within reasonable limits for a communication system. Masking can be destructive to the processing of individual patterns and some of the difficulties that exist in revealing the constructive aspects of integration.

Jane Collins, M., and Richard, R.H. (1985): Categorical Perception of speech sounds via the tactile mode. JSHR, Vol.28, Pg. 594-598.

This present study was done to determine whether or not tactually delivered analog speech/sounds could be categorically perceived and if so, to compare/tactile to auditory boundaries along a VOT (voice onset time) continuum, using a classical discrimination paradigm. In designing the

present study, it was assumed that a peak in a discrimination function would provide evidence of categorical perception via the tactile mode and the absence of peak would be indicative of noncategorical perception. VOT was selected as the dimension for the physical continuum for a variety of reasons - (1) VOT information is easily extracted from tactile devices. (2) it was assumed that the temporal information carried by the low frequency voicing cue is transmitted by a tactile aid. Four normal hearing adults (speaking English) were taken as subjects. Stimuli were synthetic syllables along a /ga-ka/ continuum. The entire continuum was presented with VOT varying from 10 to 105 milliseconds and the subjects were asked to identify the point at which perception changed from /ga/ to /ka/ or vice-versa. VOT difference was found to be 15-20 msec,. On tactile discrimination tasks. Honcontinuoug discrimination along a continuous physical dimension is indicative of categorical perception.

The results indicated that speech signals delivered by tactile stimulation; can be categorically perceived as on a VOT continuum. The boundaries for the volced-volcolecs distinction fells at longer VOTs for tactile than for auditory perception. We can infer from this study that categorical perception of speech signals is not unique to auditory system alone. This study has one clinical implication that children

having longer than normal VOT boundaries tended to be ones with profound hearing loss. It may be possible to apply the results of the present study to clinical differentiation of children who can and cannot utilize the auditory mode for communication.

Voiced-voiceless distinction would be made inaccurately by the tactile system, with signals perceived auditorily as voiceless, falling in voiced category tactually. Ideally, preprocessing should compensate for this error. However, one limitation of this study is that it did not account for the perceptual distortion, which is one of the limitations of tactile systems.

Brooks, P.L., Frost, B.J., Mason,J.L., and Chung, K. (1985): Acquisition of a 250 word vocabulary through a tactile vocoder. JASA, Vol.77, Pg.1576-1579.

This experiment reports of a subject who had received additional experience with the tactile vocoder. The following experiments summarize the performance during and after acquisition of a 250 word vocabulary. One female graduate student with normal hearing participated in this study. Previously, this subject had received 55 hours of word training and 20 hours of generalization and discrimination training

using the tactile vocoder. The subject had already acquired a tactile vocabulary of 150 words, before, the experiment began. The procedure used for learning the 100 additional words was modified in the following three ways: (1) new words were introduced ten at a time instead of five (2) new words immediately became part of the stimulus list, instead of being learned to criterion before being added to the total stimulus list (3) criterion was decreased from 80% correct to 76%. Another experiment was designed to determine, whether the subject could discriminate the words within the significantly confused pairs.

In this study, a normal subject was able to continue learning to recognize words, presented as tactile patterns, at a similar rate to that found in previous experiments. Discrimination tests indicated that increased training may eliminate many of the significant confusions.

The consistent errors, the subj ects made, indicated that the system may be modified in the future. In the instrument, since the speech signal is divided into frequency bands, there is no single channel that indicated the overall change in amplitude of the signal over time. Unvoiced fricatives were not transmitted through the system effectively, due to their low.amplitude. The results of this experiment are, however, sufficiently encouraging for the steps to be taken in further research.

increase dramatically as a function of both standard frequency and signal duration. The Weber fraction for a 248 Hz standard increased as interstimulus interval was decreased below 300 msec. By contrast, Interstimulus interval has little effect on sensitivity for standard stimuli of 48 Hz and 100 Hz.

The results of the first experiment suggest limitations in thet actual resolution of frequency of electrocutaneous stimulation, since the study was carried out with 300 ma Interstimulus Intervals. This experiment did not specify the exact refractory period for these electrocutaneous stimuli. The discrimination outcomes of the study, may not be directly due to frequency variation, but to other factors that may change with frequency (eg. total change delivered, depth of current flow, current spread).

Both the experimental results suggest that frequency encoding of intensity in an electrocutaneous vocoder is most effective for frequencies below 148 Hz. This is because adaptation of skin might take place and may show large refractory periods. Overall, this study holds some importance, because it tends to set or suggest guidelines for possible intensity coding schemes for future electrocutaneous vocoder designs which need not depend only on optimization of single electrode stimulation, but also on aspects of pattern perception within multiple electrode arrays.

Pickett, J.M., and McFarland, w (1985): Auditory implants and tactile aids for the profoundly deaf. JSHR, Vol.28, Pg.134-110.

This paper reviews data on speech perception via implanted electrodes and via tactile aids. The two approaches are compared in terms of the amount and types of aid provided to communication. The authors have discussed the performance levels with multi-versus single-channel implants, promontory electrical stimulators versus implants, use of minimal residual hearing, implants for children and the possible design of complementary systems combining auditory implant and tactile information.

The authors have dealt with two main issues -

1. Implant versus tactile,that is how does speech reception result with the best implant system compared with those for the best tactile system? They have dealt with the best or potential performance rather than the simpler, more limited aids.
2. Multi-channel implants versus single-channel implants, that is, whether multi-channel systems are significantly better compared to single-channel type. This issue is motivated by concerns of clinical and system complexity.

However, it appears from the above data that at present, and for the forceable future, neither approach can provide more than a modest aid to lipreading. Speech reception test results from multi-channel-implanted subjects are better, on the average, than for single-channel subjects. However, the best single—channel results are comparable to the best multi-channel in test, using simple sentences. There is great variation among subjects, with the same implant. Tactile aid performance by highly practiced subjects seems comparable to that of the better implanted subjects.

The authors have compiled the literature and have drawn some Important conclusions about the implants and tactile devices.

1. Speech perception of single words with multi-channel implants is better than multi-channel implants. However, its tests with sentence ie material, the best subject with a single-channel implant is roughly equal to the average with multi-channel implants.

2. Most implantees could be characterized as highly dependent, for everyday speech communication, on lipreadlng, together with, using their implant. However, there is a very wide range of performance even among subjects with the same implant.

3. Test results on the best single-channel implants suggest that the temporal information in the speech wave can be the main source of cues supporting aid performance.

4. The best implant performance is not substantially better, at this time, than for practised subjects with multi-channel tactile speech system.

5. Testing with open word or sentence material has the inherent problem that the factor of the subject' s knowledge of the language can overbear factors of the design of the aid.

6. The current evidence on children's performance, all with single-channel implants, indicates that they are receiving the same information as adults with single-channel implants time and intensity information.

7. In view of the difficulty of accurately establishing the degree of residual hearing in young deaf children and the limited benefits of present implants, they favor the early fitting of hearing aids and tactile aids, rather than implants*

Reed, C M., Rabinowitz, W.M., Durlach, N.I., and Braida, L.D. (1985): Research on the Tadoma method of speech communication. JASA, Vol.77, No.l, Pg.247-257.

This paper includes the ongoing research program on Tadoma. In section-I, speech perception results are obtained on a deaf blinds, highly experienced users of Tadoma.

The section-II deals with an approach to augment performance, obtained on Tadoma by incorporating a supplementary tactile display on tongue position.

The section-III deals with the description of the development of synthetic Tadoma system in which signals recorded from a talker's face are used to drive an artificial face. In Tadoma, speech is received by placing a hand on the talker's face and monitoring action, associated with speech perception, speech production and linguistic abilities of deaf blind individuals, highly trained in Tadoma. This research has demonthat good speech reception is possible through the tactile sense. Performance is roughly equivalent to that of normal listening in noise or babble with a S/N ratio in the range 0-6 dB. It appears that the principal cues employed are lip movements, jaw movements, oral airflow and laryngeal vibrations and that the errors which occur, are caused primarily by inadequate information on tongue position.

The results of Section-I indicated that the abilities of a deaf-blind individual to receive continuous speech via the Tadoma method are not based on exceptional sensitivity to differences, among the tactile patterns* associated with speech segments.

Modified Tadoma leads to significantly improved performance on the Identification of segments that will lead to significantly improved performance on sentence comprehension.

Fair amount of success was depicted by synthetic Tadoma. Some relevant factors behind this success are -

1. Nature of the Tadoma display - a talking face.
2. The extent of training.
3. The ume of the hand for receiving the tactile input.

A talking face may be a good tactile display for two reasons.

1. Rich display in comparison to vibratory arrays.
2. Information is simultaneously presented along a variety of different dimensions (gross movement of articulators, airflow, vibration, etc). The perception which involves a variety of mechanisms (surface and deep touch receptors, muscles and joint receptors, etc.)
3. The signals that the talking face displays are directly related to the articulatory process of speech production.

A synthetic Tadoma system is composed of an artificial face, that is driven by computer controlled signals, derived from sensors of a talker* s facial movements, that appear to provide the primary cues for understanding speech via Tadoma.

The criterion for developing synthetic Tadoma was that performance would be similar to natural Tadoma. It can be used for comparison studies. It can be studied, how the performance is affected by various transformation that cannot be achieved with natural Tadoma.

The authors believe that transformation of Tadoma will lead to substantially Increased understanding of Tadoma and tactile speech communication, in general. Three transcriptions are -

1) The input information, held constant, and while the display is varied. The display can be redesigned for the stimulation of abdomen.

2) Display (artificial face), held constant and the input information is varied. That is, spectral information can be presented on the artificial face.

3) Both held constant, the intermediate signal processing is varied.

That is, improved performance by sharpening the signals.

In the coming years of study, other modifications of interest could be, like disabling selected input, varying rate of presentation, low pass filtering and decreasing th@ amplitude quantization of certain control waveforms (those associated with the movement of the articulators) and the presentation of selected combination of principle components of these waveforms.

Grant, K.W., Adrell, L.A., Kuhl, P.K., and Sparks, D.W. (1986): The transmission of prosodic information via an electrotactlle speech reading aid.Ear & Hearing 7,Pg 328-335

The primary goal of the current study was to assess the effects on speech reading when voice fundamental frequency information is transmitted to the skin via an electrotactile speech aid, rather than to the ear. The authors made several measures, using the aid in isolation and in combination with speech-reading. Variations in voice fundamental frequency were extracted from naturally produced speech samples and transmitted to an electrocutaneous display, consisting of ten electrodes, arranged in a linear array along the forearm.

In experiment-I, the identification performance for rising versus falling sentence inflation via the aid alone or in combination with speech reading was evaluated. In

experimental-II the identification of sentence stress and rhythm via the aid alone, was evaluated. In experiment-Ill, the rate of speech-reading with and without the aid was evaluated, using the connected discourse teaching procedure. Acoustically isolated room with adequate lighting was used. Profoundly hearing-impaired subjects and one normally hearing listener were the subjects. After 20 hours of speech reading training in connected discourse tracking procedure, both subjects showed higher tracking rates and faster learning rates with the aid, than without the aid. Patterns of prosody which are not easily speechread, are readily available with the aid. The results seems to be encouraging as all three linguistic aspects of Fo were perceived with a very high degree of accuracy after relatively small amounts of training. Changes in Fo were encoded as changes in stimulus location.

The ability to combine speech reading and tactile speech cues at high rates of communication has not always been found in previous tactile aid studies. The clinical implication of this study is that we can recommend a tactile aid of this type, be incorporated into speech-reading training programs for the profoundly deaf, several problems concerning the current Fo encoding scheme need to be considered. The present study has some drawbacks in the sense that the

training periods were short. Since only two subjects were tested, and only one of these post-lingually deaf, any conclusions drawn from the present results must be viewed as preliminary. Using this sort of aid, we cannot be sure whether the subjects were losing important transitional information. However, the excellent results obtained with this study will encourage long-term evaluations with other improved electro tactile aids.

Plant, G., and Spens, K.E. (1986): An experienced use of tactile information as a supplement to lipreading: An evaluation study. STL-QPSR, No.l, Pg.87-110.

The present study is a single case study. A 48 year old Swedish male, deafened by meningitis at age 8 years has developed a unique method whereby he can perceive a speaker's laryngeal vibrations and use this information, as a supplement to lipreading. The method consists of placing his hand on the speaker's shoulder with his thumb pressed lightly against the side of the neck. Testing of the subject, using this method revealed improvements in lipreading ability with materials ranging in complexity from nonsense syllables to connected discourse. Testing via tactile stimulation alone, showed that the subject was able to perceive consonant voicing almost perfectly (99.3% correct), and consonant

manner of articulation was identified at a high level of proficiency. Performance with materials assessing perception of syllables in words and sentences and emphatic stress in sentences was also relatively high. Testing was also conducted, using two experimental vibrotactlle aids. Performance with these was consistently lower than that using the subject's own method across almost all testing materials. The major finding in this study has been the great effectiveness of the subject's method of supplementing lipreading by tactile reception of laryngeal vibrations.

The subject's performance overall gives a striking example of the great potential value of tactile information to lipreading performance. Perhaps, the most important factor, contributing to the subject's success is the long period of time he has been using this method. Other advantof the method include the close proximity of receiver to speaker which it necessiates. This ensures that optimal visual cues are available for lipreading.

This study has highlighted the need for a number Of future research projects, like detailed examination of the subject's speech perception and a study of his speech production. The quality of the subject's speech has not been discussed in this paper but it does appear to be of an extremely high standard, especially in the production of. suprasegmental contrasts.

Weisenbmrg, J.M. (1986); Sensitivity to amplitude - modulated Vobrotactile signals. JASA, Vol.80, No.6, Pg.1707-1715

The present three experiments measure the temporal sensitivity of the tactile system by obtaining the resulting modulating transfer functions for a number of amplitude modulated carrier waveforms. The modulating transfer function, as used in linear system analysis, describes the output response of a system to a given input signal. In the present, case, the response of the tactile system is measured for a range of temporally varying (amplitude-modulated) vibratory stimuli. The resulting transfer function plots modulation depth required for threshold detection of modulation as a function of the rate of modulation.

In the first experiment, the response of the tactile system to sinusoidal amplitude modulation of sinusoidal vibrotactile carrier signals was measured, in an attempt to outline the basic features of the temporal modulation transfer function for the system. Sinusoidal carriers were chosen because of their frequent employment sensitivity. Three normal hearing subjects were chosen and they were asked to indicate the interval that contained the modulated signal. The results indicated that the subjects could indeed perceive amplitude modulation with a fair degree of sensitivity, with peak sensitivity occurring at frequencies in the middle of the range tested (40 Hz - 250 Hz).

The second experiment was done to investigate the possibility of sideband resolution, and to determine whether overall modulation sensitivity is worse when non-sinusoidal carrier waveforms are used, sensitivity to amplitude modulation of broad band noise carriers was measured. Three normal hearing subjects were taken and ten samples of pseudorandom shift-register noise was taken The subjects were asked to choose the interval containing the modulated signal. Modulation depths were varied and with the frequencies ranging from 5 Hz-200 Hz.

Results indicated that sensitivity is best at 20 Hz and declines above and below this value. A more notable finding is the poor overall level of performance for the broadband noise carriers as compared to sinusoidal carriers.

The aim of the third experiment was to compare vibro-tactile performance with broad band and narrow band noise carrier waveforms. The results indicated that modulation sensitivity was better with narrow band carriers for modulation frequencies between 20 Hz and 80 Hz, but at very high modulation frequencies, performance was better with the broad band carrier.

In fact, the overall levels of tactile performance with broadband and narrow band noise carriers are quite poor, suggesting that the use of amplitude modulation as

hearing subjects adults served as subjects in the experiment. Mean age of the subjects was 23 years. The Fonator was selected as the single-channel device and the multichannel device, used was the tactual vocoder. A masking generator was used to deliver noise in order to cut-off the auditory sense. After a training of 3 to 4 weeks, the subjects were evaluated.

In general, subjects who were tested with single-channel device, tended to have higher scores on the syllable number and syllable-stress tasks, than those who were tested with the multichannel device; this difference was not observed as clearly for the intonation task. The results clearly indicated that a single channel vibrotactile device often provided better cues for the identification of certain suprasegmental features of speech, because of preservation of waveform - envelope Information. It was found that the performance on the post-test was poorer for all trained subjects compared to their final training results, suggesting that cues learned in training were not readily transferable to new stimuli, even those with similar prosodic characteristics. Overall, the study provides a notion that certain prosodic features of speech may be conveyed more readily when the waveform envelope is preserved.

In this study, the duration of the training was too short to produce any significant change in performance of

trained subjects, compared to those with no training. The fact that some untrained subjects showed small improvements on the post test as well, suggests that even very limited experience with tactile stimulation provides some information. Even, the perception of suprasegments may be limited by the nature of the tactile stimulus received by the subject.

These results may not hold good across other single channel and multi-channel instruments. In the short-term, the perception of certain suprasegmental aspects of speech is moderately enhanced by waveform envelope of speech signal and this finding can be utilized to design tactile aids for deaf, in future.

Plant, G.L. (1986): A single channel transducer vibrotactlle aid to lip reading. STL-QPSR, 1, 41-63, Haskins Laboratories Report.

In this paper, the authors describe results, obtained on four deaf subjects, using a single transducer vibrotactile aid, presenting Fo cues and information, as to the presence/absence of high frequency energy. The subjects were tested, using a vibrotactile aid to lip reading, presenting voicing information and a cue to signal the presence of high frequency

energy. The subjects were tested, using a vibrotactile aid to lip reading, presenting voicing information and a cue to signal the presence of high frequency consonants. Testing at the level of consonant perception presented lip reading alone, and lipreading supplemented by the aid showed improvements in the perception of consonant voicing and manner of articulation in the aided condition. Testing at the word and sentence level showed differing results for the subjects, completing the tasks. A congenitally deaf subject with a history of non-hearing aid use showed no improvements in the aided conditions whereas another subject with a history of very successful hearing aid use, evidenced by improvements in the aided condition for both sets of materials. Testing at the level of connected discourse revealed improvements in the aided condition for two subjects, but equivalent scores aided/unaided for the subject with limited hearing aid experience. Testing in the tactile aid alone condition showed that subjects were able to perceive the presence/absence of /s/ and word syllable number and type with a high degree of proficiency.

The results obtained in this study indicated that the experimental aid offers much information which can serve as a very useful supplement to lipreading. The subject's performances on the two consonant perception tasks showed that

many of the confusions confronting to the lip reader can be overcome by an aid, presenting Fo Information as either a fixed or variable frequency. Features which cannot be perceived visually, for eg. voicing and nasality, can be reliably detected with the tactile aid. Reliable information as to consonant voicing and nasality also seen to offer much useful information for the development of speech production skills. The subjects also evidenced much improved recognition of the sibilant consonants in the aided condition. A reliable means of sibilant detection such as is provided by the present aid would thus appear to be a most useful feature for both speech perception and production training. The study has not answered the problem of whether Fo should be presented as a fixed or variable frequency. In part, this is due to the varying amounts of the testing program completed by the individual subjects. Limited exposive to the aid should be taken into consideration.

Actually, the aid had assisted in the development of more normal speech patterns although, it should be noted that the subject's speech is still relatively unintelligible. The experimental aid, no doubt, offers useful information for enhanced speech communication.

Bersistein, L.E. et al. (1986): Child and adult vibrotactile thresholds for stimulation and pulsatile stimuli. JASA, Vol.80, Pg.118-123.

Three experiments were performed to obtain vibrotactile sensitivity thresholds from hearing children and adults and from deaf children. An adaptive two interval forced choice procedure was used to obtain estimates of the 70.7% point on the psychometric sensitivity curve. When hearing children of 5-6 and 9-10 years of age and adults were tested with sinusoids and haversine pulse stimuli, at 10, 100, 160 and 250 Hz pulses per second respectively only the 10 Hz stimulus resulted in an age effect. For this stimulus, young children were significantly less sensitive than adults. When sinusoids were again tested at 20, 40, 80 and 160 Hz, a small overall effect of age was observed with a significant effect only at 20 Hz. Two prelingually profound deaf children were tested with hav rsine pulses per second. Both children were at least sensitive to the tactile and the adults. Pulsatile stimulation, as compared to sinusoidal stimulation exhibited relatively flat threshold versus frequency function. The present results, demonstrating no age effect for pulsatile stimulation and similar performance for deaf

and hearing children, suggest pulsatile stimulation approximately for vibratory speech communication aids for the deaf.

The results have shown that the thresholds curves for adults and children are the same, when stimulation is haversine pulses. Further, the shape of the curve is quite flat, in comparison with curves, resulting from sinusoidal stimulation. These results are in agreement with reports published earlier.

In the area of audition, it has been found that young children have poorer pure tone sensitivity than older children or adults. Information about synchronies and asynchronies in development across sensory perceptual systems can help to resolve questions about the relative continuation of physiologic and perceptual or cognitive factors to developmental effects. Results of the current study suggest the following:

1. Pulsatile stimulation does not in age effects, nor large threshold shifts as a function of pulse rate and therefore preferable for implementation of a vibrotactile communication aid.

2. Young children are less sensitive than older children or adults at low sinusoidal stimuli (ie in the vicinity of 10 and 20 Hz.

3. Deaf subjects, without additional handicapping condition, do not differ from hearing adults or children, tested with haversine stimuli.

Qller, D.K. et al. (1986): Tactile vocoder in a multisensory program training; speech production and reception. The Volta Review, Vol.88, No.1, Pg.21-37.

This article describes an elementary and preschool program, using a vibrotactile and electroeutaneous vocoder in speech reception and production training with 13 profound hearing-impaired children (3-6 years). The training approach was electric, presenting speech information through the senses of touch, vision and audition in combination and in isolation. Reception (discrimination, identification and comprehension) and production (imitation and functional use) were trained with syllables, words and simple sentences. Results indicated that progress in speech communication was not seen prior to training with tactual vocoder. Both electrocutaneous and vibrotactile vocoders were found to be useful aids in training speech production and reception with the profoundly hearing-impaired children, in this study. This study encourages further exploration of the use of tactual aids to improve speech reception in the profoundly hearing-impaired.

Weisenberger, J.M, et al. (1987): The role of tactile aids in providing Information about acoustic stimuli. JASA, 82, 906-916.

Devices that convert sound patterns into patterns of vibrotactile stimulation have been shown in laboratory and clinical studies to enable persons to appreciate many aspects of the acoustic environment and thus are of potential benefit to deaf persons. In the present article, the authors have presented a framework, which is outlined for describing normal listening situations as a hierarchy of tasks requiring increasingly complex analysis of the acoustic waveform, including sound detection, environmental sound identification, syllable rhythm and stress categorization, phoneme and word identification and comprehension of connected speech.. The types of benefits, provided by tactile aids in each of these tasks are exemplified, using data from studies of single-channel commercially available devices and multi-channel tactile vocoders in the laboratories.

Levels of processing of acoustic stimuli

Task	Waveform analysis
1) Detection	Presence of energy
2) Localization	Interlours intensity differences

3) Identification	
a) Environmental sounds	Amplitude envelope
b) Words	
i) Syllable rhythm and aress	Amplitude envelope
ii) Whole word identification	Fine spectral/temporal features.
iii) Connected speech	Fine spectral/temporal features.

In summary, all these results suggested that the tactile aids can provide helpful information in a variety of listening flasks, including detection, localization, environmental sound identification, etc. Finally, an examination of the different levels of information, extracted from an acoustic waveform by a listener, including that necessary for detection, environmental sound identification, etc, is of interest not only for the evaluation of tactile aids, but also for the assessment of any type of device, designed to provide acoustic information to the hearing-impaired patient.

Plant, G. et al. (1987): Single transducer vibrotactile aid to lip reading and speech production. Annals of Oto,Rhino and Laryngology, Vol.96, Pg. 87-99.

A single transducer hand-held vibrotactile aid has been developed and four profoundly deaf adults were trained for its use.

Two subjects have been trained with the aid presenting fixed frequency and variable intensity cues, and two, with the aid, presenting a variable frequency of constant intensity. The results showed that the aid provided information for both speech perception and production. The scores obtained for syllables, words, sentences and connected discourse perception, when the vibrotactile aid supplemented lip reading were significantly better than those, obtained, when the same materials were presented via lipreading alone. Spectrographic analysis of the speech of a congenitally deaf adult's pretraining and post-training of the aid revealed improvement in both syllable duration and sibilant production. The results of this study seem quite significant in the development of a wearable version of the aid.

Risberg, A. (1987): Speech coding in a single-channel implants and a comparison of results for auditory, tactile and electrical stimulation. Annals of Oto.Rhino and Laryngology, Vol.96 Pg 65.66.

The aim of speech coding in a sensory aid for the deaf is to adapt the natural acoustic signal to the capacity of the sensory channel used. The authors' experiences, with deaf persons, using a simple tactile aid, or an extracochlear

implant indicates, however that this assumption, is not valid. It is not likely that speech understanding without lipreading, can be obtained in simple, single channel systems. Results of the coding evaluation reveals that -

1. Intensity variation of 20-30 dB must be transmitted.
2. Fundamental frequency variations in speech are important and hence the systems should be based on the extraction of Fo.
3. Gross spectral information can be transmitted by means of single frequency, gives good support during lipreading and will be useful for everyday sounds.

Blarney, P.J. et al. (1988): Phonemic information transmitted by a multi-channel electrotactile speech processor, JSHR, Vol.31, Pg.620-629.

A wearable electrotactile speech processor was evaluated by the authors. Seven normally hearing and four hearing-impaired subjects were taken up for the study. The processor estimated the fundamental frequency, the second formant frequency, the amplitude of the acoustic speech signal. These parameters were presented as a pattern of electrical pulses, applied to eight electrodes, positioned over the

digital nerve bundles on one hand. The device warn shown to provide useful information for the recognition of phonemes in closed sets of words, using tactile information alone. The device also supplemented lipreadlng to improve the recognition of open-set words. The recognition of duration and first and second formant frequencies of vowels and the recognition of voicing and manner of consonants were improved over recognition with lipreading alone. Recognition of final consonants was improved, more than recognition of initial consonants. These results indicated that the device may be useful to both severely and profoundly hearing-impaired people. The information presented here allows a preliminary conjecture about which segment of the hearing-impaired population may be helped by the device. It is indicated that the provision of tactile information that overlaps with auditory information from the hearing aid, also might improve recognition of voicing, duration and manner. These conjectures will require verification in further studies that involve the use of hearing as well as lipreading and the tactile device. The usefulness of the device may be improved in a number of ways. The most effective of these would probably be to enlarge the frequency range represented by the electrode array to include first-formant frequencies, and to include more electrodes so that a finer frequency resolution could be attained. This might improve the perception of vowels and consonant place.

Cowan, R.S.C. et al. (1986): Preliminary evaluation of a multi-channel electrotactile speech processor. JASA, 83, 6, Pg. 2328-2338.

The aims of the present study were to evaluate the effectiveness'of the Tickle Talker as a wearable communication aid for the hearing-impaired and to develop and evaluate training programs for use with the device. This article presented results for four hearing-impaired and seven normally hearing subjects who were trained in the use of 8-channel electrotactile aid. The electrotactile stimulation consisted of three separate components. (1) The electrode handset and connecting calde. (2) The stimulation unit, and (3) The speech processor and microphone. Speech discrimination training was carried out, using both open and close-set materials. Significant Increases in speech-training rates were noted for all subjects, when using the electrotactile aid. After 70 hours of training, mean tracking rate in the tactile plus lipreading condition was 55 words per minute, as compared with 36 wpm. for lipreading alone, for the normally hearing group. For the hearing-impaired group, the mean tracking rate in the aided condition was 37 wpm. as compared to 24 wpm for lipreading alone, following 35 hours

of training. Performance scores on CID every day sentences, consonant nucleus consonant (CNC) words, and closed set vowel and consonant identification were significantly improved, when using the electrotactile aid. Performance scores, using the aid without lipreading, were well above. Chance on consonant and vowel identification and on elements of the Minimal Auditory Capabilities Battery. The results for both open and closed set evaluation tests show increase in performance scores in the aided as compared to the unaided condition for all subjects. Familiarity with the speaker and test could have been a factor in the increased speech-tracking rates in the unaided condition, since both the normally hearing and hearing-impaired subjects show improvements. The results on the identification of vowels and consonants showed that significant phonemic information is accessible from the tactile modality and that it can be used in conjunction with speech reading to improve performance on closed set tests. The results of these studies clearly demonstrate the ability of subjects to utilize the tactile modality to obtain information, which, when combined with lipreading, can improve performance on a variety of speech tasks. The present study also highlighted the necessity of field trials of any potential device. Although,

evaluated performance of the aid in the totally deaf. Situation, the potential user population envisaged for the aid would include individuals with some residual hearing. Who would use the device in addition to hearing aids and lipreading. This study could have been extended to the use of electrotactile aid in combination with auditory and lipreading information in both adults and children.

Skinner, H.w., singer, S., Fredrickson, J., Smith, P.G., Holden, T. (1988): Comparison of benefit from vibrotactile aid for post-lingually deaf adults. Laryngoscope, Vol.98, Page 1092-1099.

The goal of the present study was to compare the benefit provided by a one or two-channel vibrotactile aid to the benefit, provided by a multi-channel multielectrode, intracochlear implant for the same post-lingually deaf adults. Four post-lingually deaf adults were evaluated pre-surgically with a one or two channel vibrotactlle aid and post-surgically, with a multi-channel multi-electrode, intracochlear implant. Although the vibrotactile aid provided awareness of sound and enhanced flow of conversation, benefit to lipreading was small on videotaped tests and speech tracking. Scores on recorded, sound-only speech tests

were not significantly above chance except in discrimination of noise from voice. With cochlear implant, benefit to lipreading was significantly greater than with the vibrotactile aid, and scores on sound-only tests were significantly above chance. Communication was markedly better with implant than with the vibrotactile aid. In counseling, those get no benefit from a hearing aid, the results of this study provide data on the amount of benefit one or two-channel vlbrotactile aids provide post-lingually deaf adults who are subsequently implanted.

Data obtained with speech tracking procedure clearly shows the difference between communication with the vibrotactile aid and the cochlear implant. By focusing on the mean difference score between lip reading done and lip reading with a prosthesis, the variability contributed by changes in the physical and mental states of the talker and patient across days and differences in passage difficulty is minimized. For post-lingually deaf adults who meet the criteria for implantation, the multi-channel, multi-electrode, intracochlear implant provides the possibility of much greater benefit, compared to a one or two channel vibrotactile aid.

There are post-lingually deaf adults who do not meet the criteria for implantation or do not want surgery. A

one or two-channel vibrotactile aid would put then back in touch with the world of sound and may bring limited enhancement of lip-reading. A multi-channel vibrotactile aid may be more beneficial. The results of this study provided data on the amount of benefit these aids provided post-lingually deaf adults who are subsequently implanted. Although prospective cochlear implant patients should know about vibrotactile aids as an alternative to surgical implantation* the possible benefit of a multi-channel, multi-electrode, intra-cochlear implant for surpasses that of the one or two channel vibrotactile aid.

Carney, A.E. (1988): Vibrotactile perception of segmental features of speech - A comparison of single changed and multi-channel instruments. JSHR, 31, Page 438-448.

The purpose of the current investigation was to determine whether the tactile perception of segmental features of speech was enhanced more by presentation of the waveform envelope cues, provided by a single channel tactile aid, or by the presentation of spectral cues, provided by a multi-channel tactile aid. This type of Investigation would permit a comparison of two different types of tactile stimulus arrays in the same laboratory, keeping stimuli and procedures constant. A second purpose of the experiment was to compare

these two devices as aids for lip reading for segmental stimuli. Two groups of six adults with normal hearing served as subjects in this experiment, with a mean age from 18 to 25 years. The experiment actually compared the recognition performance of artificially deafened listeners for segmental stimuli presented through a single channel tactile device and through a 24-channel vocoder. Both consonant and vowel stimuli were tested under visual condition only, tactile condition only and visual + tactile conditions. Each subject received a pretest, eight 2-hour training sessions, and a post-test. Results indicated no significant differences between subjects* overall recognition performance with two different tactile devices. Analysis of consonant confusions showed that both devices transmit the features of voicing, manner and place of articulation in a similar fashion. In contrast to earlier studies, results donot support the notion that preservation of the waveform envelope of speech is necessary for the transmission of segmental features of speech. These results also suggest that tactile perception of segmental features may not be attested significantly by the tactile array chosen.

Because of the short-term nature of training in the experiment, the final identification performance of objects

on the post-test should not be regarded as asymptotic. In this short-term training experiment, the addition of tactile cues to visual cues did not increase identification performance significantly ever the visual only performance for either vowels or consonants. A lack of significance may be due, in part, to a type of ceiling effect in the visual only condition. Subjects in the multi-channel group, had generally high visual scores, especially for vowels. However, the consonant identification functions showed very slightly higher identification performance in the VT condition, suggesting a trend toward incorporating visual and tactile cues with more training. In summary, the results of this experiment do not support the notion that either waveform envelope Information or spectral Information is superior in providing segmental tactile information to subjects.

Arthur Boothroyd (1989): Developing and evaluating a tactile speech reading aid. The Volta Review, Vol.91, Pg.101-112.

The work described in this paper is based on the hypothesis that tactile presentation of Fo (Fundamental frequency) can be as effective as auditory presentation as an aid to speech reading. This hypothesis was tested, using a device that presents Fo as position of tactile stimulation of the

arm, timing an array of 8 or 16 vibrators. The evaluation process consisted of (a) auditory stimulations to confirm that the Fo patterns can provide the expected enhancement, (b) Experiments on the perception of phonetic contrasts via the tactile device, (c) Psychophysical studies to confirm that subjects are sensitive to changes in pattern of tactile stimulation, provided by a device, (d) Sentence perception studies using post-lingually deafned adults.

After training with the device, the adults experienced a reduction of speech reading error of between 25% and 50% This Is encouraging, though not as the 40-90% reduction of error experienced by normal hearing adults, presented with Fo auditorially. Results of the phonetic level and psychophysleal experiments suggest that some of the information, the tactile device provides, could be conveyed via a single-vibrator, but that a 16-channel display is probably more effective.

The description of the device has been given adequately. The device has two parts. The Ist part is a speech processing unit, containing (a) a microphone (b) analog circuits for converting the output of the microphone into square waves whose frequency equals voice Fo (c) a digital computer programmed to measure the duration of each cycle and to route

the next cycle to the appropriate one of 8 or 16 output channels (d) the amplifiers needed to drive the output vibrators (e) the rechargeable batteries needed to power the system. The 2nd part of the device is the vibrator array, designed to be attached to the forearm with elasticized straps. The array can contain either 8 or 16 vibrators, each consisting of a tiny solenoid actuator, specially modified for this application. The internal computer is controlled by a program that remains in memory when the unit is switched off. This program is written in such a way that equal multiplications of frequency produce equal movements of stimulus on the skin.

A number of important conclusions drawn in this study are -

1) Auditory presentation of Fo significantly enhances speech reading at the sentence level.
2) Fhonetic information, provided by Fo contours tengs to be that which is missing from the visual stimulus. This is hardly surprising, given the facts that Fo is a parameter of voiced sounds and that the activities of the larynx are Invisible.
3) The quantization resulting from representing smooth Fo contours in terras of a number of discrete steps reduces the usefulness of the contours as a supplement to speech reading.

4) A single channel display of Fo provides a frequency resolution of about 9.25 octaves at the finger tip. With frequency expansion in a speech processor, the effective number of channels could be increased. Of more concern is the unsuitability of the finger tip for a wearable sensory aid and the fact that the sensation accompanying tactile Fo is very subtle.
5) When Fo contours are presented tactually, they provide access to some of the phonetic information, that is missing from the visual stimulus. Both single-channel stimulation of the finger tip and 16-channel, spatial stimulation of the forearm provided access to those features cued by the presence, time of onset, and duration of voiced sounds. Only one spatial display, however, gave evidence of providing access to features cued by patterns of variation of Fo over time.
6) Spatially represented, tactually presented information about Fo can provide measurable speech reading enhancement after training, though not, as much as provided by auditory Fo to normal hearing subjects. This conclusion was based on the performance of only three subjects and clearly needs to be investigated further.

Studies should also be done to notify individual differences, the effects of changing the number of channels

in the spatial display, the effects of adding other tactually coded speech cues and even the effects of changing the locus of stimulation. It should be noted that the stimuli used in these experiments were either synthetic or derived from ideal Inputs - either speech in quiet or output of a throat microphone. A wearable sensory aid must be capable of dealing with real speech, produced by a variety of talkers at a distance of several feet, and often in noisy environments. Physical evaluation of device performance is, therefore another crucial of component of sensory aids research. If a wearable device gives a less than satisfactory performance, it is important to know whether the fault lies in the device Itself ie. that is not processing the speech input adequately or in the design concept, ie., that the Information being extracted from the speech or the form in which it is being recorded is inappropriate. The device described here, has yet to be fully evaluated in terms of its potential to provide sufficient speech reading enhancement under more natural input conditions,

Michael, P.L., Kimbrough, 0., and Rebecca, E.E. (1939): Portable tactile aids for speech perception; The Volta Review, Vol.91, No.6, 113-126.

Recent technological advances have made it possible to construct wearable aids that present information to the

tactile sense. This development is important, because it allows for hearing-impaired individuals - particularly of children - greater acquisition of tactual speech knowledge, since they may now use the aids in a wider variety of contexts throughout the day. The authors have reviewed the experimental use of portable tactile aids in speech perception.

The authors talk about Tactaid II, Tactald V, Tacticon 1600 and Tickle Talker as portable aids.

The tactile spectrograms provided by these devices Include information about a number of acoustic features of speech. All indicate duration. Intensity, frication and plosive energy. Those, with larger number of channels transmit frequency locations of concentrations of energy and are felt as concentrations of stimulation on the array or as patterns of rapid movement across the array, respectively. Instead of the frequency spectrum of speech. Tickle Talker presents a collection of features - Fo, F2 and amplitude on the skin. The authors have reported studies of portable tactile aids and have grouped them into three categories:

1. Those emphasizing training subjects to perceive speech through touch.
2. Those emphasizing the additive benefit of tactile aids when combined with speech reading, aided hearing or both speech reading and aided hearing.

3. Comparisons of subjects performance using different tactile aids on the same tasks.

Almost all subjects could discriminate phonemes, after suitable training. Real speech could be perceived, only after excessive training. Subject experienced gains When a portable tactile aid, was added to either speech reading, aided hearing or a combination of speech reading and aided hearing. The results indicated that regardless of differences in device characteristics (ie. the number of channels or the type of information conveyed), portable tactile devices provided subjects with speech information that was complementary to that, provided by speech reading and aided hearing.

The confounding of factors such as processing schemes and channel numbers in the studies, comparing electrocutaneous and vlbrotactile stimulation demands that further empirical work be conducted. It is important to ascertain the extent to which the stimulation types produce different levels of subject performance on speech perception tasks to determine Whether there is a superior stimulation type. The development of portable tactile aids has been a major step forward in the effort to augment the speech perception of the hearing-impaired.

Cowan, R.S.C., Alcantara, J.I., Whitford, L.A., Blarney, P.J. and Clark, G.M. (1989); Speech perception studies using a multichannel electrotactile speech processor, residual hearing and lipreading. JASA, Vol.85, Page 2593-2607.

The authors have reported three studies on the speech perception of normally hearing and hearing-impaired adults using combinations of visual, auditory and tactile input. The first study examined the contribution of tactile information to speech recognition in the combined tactile plus auditory (TA) and combined tactile plus auditory plus lipreading (TLA) conditions, following training in combined modalities. The second study assessed the contribution of tactile information to combined TA and TLA speech recognition using different frequency ranges of available low frequency auditory Information. Both of these studies were conducted with normally hearing subjects listening to a degraded auditory signal (low pass filtered speech plus masking noise).

The final study measured the tactile information contribution to combined TA and TLA speech perception for three hearing-impaired adults.

In study-1, mean scores for four normally hearing subjects showed that addition of tactile information, to

either audition alone or lipreading plus audition resulted in significant improvements in phoneme and word discrimination scores. Information transmission analyses demonstrated the effectiveness of the tactile aid in providing cues to duration, Fl and F2 features for vowels, and manner of articulation features for consonants, especially features requiring detection and discrimination of high frequency information.

In study-2, 6 different cut-off frequencies were used for a low-pass filtered auditory signal. Mean scores for vowel and consonant identification were significantly higher with the audition of tactile input to audition alone at each cut-off frequency upto 1500 Hz. The mean speech tracking rate was also significantly increased by the additional tactile input upto 1500 Hz.

In study-3 examined speech discrimination of 3 hearing impaired adults. Additional information available through the tactile aid was shown to improve speech discrimination scores; however the degree of increase was inversely related to the level of residual hearing. Results indicated that the electrotactile aid may be useful for patients with little residual hearing and for severely to profoundly hearing-

impaired, who could benefit from high frequency information presented through the tactile modality,but unavailable through hearing aids.

In this study, although the training program has been effective in Improving feature recognition as shown by closed-set vowel and consonant scores, more emphasis needs to be placed on the communication tasks, before similar improvements with open set materials are analyzed*

Lynch, P.M. et al. (1989): Multi-sensory speech perception by profoundly hearing-impaired children. JHSD, Vol.54, Page 57-67.

The present research was designed to explore the effect of unimodal tactual training on hearing-impaired children's ability to generalize tactual information to novel speech stimuli. Speech perception was examined in both unimodal and multi-modal contexts with children in an extensive tactual stimulation training program. Four children in study-1 (5-7 years) and 4 children in study-2 (8-11 years) received unimodal (tactual) word recognition training with tactual speech perception aids. Two of the subjects in study-1 were trained with a 2-channel device and 2 were trained with a 16 channel aid. All the subjects in study-2 need a 16-channel aid.

Following training, subjects were tested on a list, containing equal number of trained words in 3 conditions:

a) aided hearing alone

b) tactual aid alone

c) combined.

Results indicated that the subjects performed better in the combined condition of both trained and tactually presented new words, providing evidence for significant sensory integration following unlmodal training. Further research is needed to determine relative amounts of unimodal and multimodal training that are optimal to achieve rapid learning and successful integration of multi-sensory information.

Lynch, H.P. et al. (1989): Multi-sensory narrative tracking by a profoundly deaf subject, using an electrocutaneous vocoder and vibrotactlle aid. JSHR, Vol.32, Pag* 331-338.

The present research is designed to explore the additive benefit of tactual speech information to that from lipreading and aided hearing in a narrative tracking task with a profoundly deaf adult, in the 1st phase, tracking performance was examined, using the Tacticon 1600, electrocutaneous vocoder. In the 2nd phase, tracking procedure was investigated when the tactile II vibrotactile aid was used.

In the final phase, both tactile devices were used, the performance with them, was compared to when lipreading and aided hearing were used with out tactile information.

The results showed that the subject's ability to integrate tactual cues with these from aided hearing and lipreading were significant and it was attributed to the efficacy of unimodal training,that the subject had received.

Appropriate statistics were used in this study. Only one drawback is that this was a single subject study. Although profoundly deaf subjects are able to integrate tactual and auditory cues,wien identifying single words from a closed set, additional evidence is needed to indicate whether such integration may occur in the perception of running speech.

Lynn*, E.B. (1989): Single channel vibrotactile supplements to visual perception of intonation and stress. JASA, Vol.85, Page 397-406.

Two experiments were conducted to explore the effectiveness of a single vibrotactile stimulation to convey intonation and contrastive stress. In the first experiment, artificially deafened normal hearing subjects judged stress and intonation in counterbalanced visual-alone and visual tactile

conditions. Benefits to speech reading were significant but small. No significant differences among six transformations of voice fundamental frequency were observed. In the second experiment, only the tactile stimuli were presented. Significant differences emerged among the transformation with larger differences for intonation than for stress judgements. Surprisingly, tactile alone intonation identification was more accurate than visual-tactile, for several transformations. In conclusion, single-channel doding of Po is a viable option for tactile aids to speech reading. One avenue for future research would be to investigate combining effective single channel codes for Po with spatial codes that convey other types of speech information, such as speech spectra.

Hong,Z.Tan., William, M.R., Nanthaniel, l.D. (1989); Analysis of a synthetic tadoma system as a multidimensional tactile display. JASA, Vol.86, No.3, Page 981-988.

The study of tactile communication of speech serves several purposes. First, for those who are both blind and deaf, such study will help make possible, the use of another sense modality for speech communication. Second, one study will lead to more insight into how the tactile sense works.

Finally, the study improves the basic understanding of speech communication. Some characteristics of Tadoma, that might be responsible for it's exceptionally good performance are:

1) A face 'rich' multidlmentional tactile display;
2) The display directly represents the articulatory process;
3) The hand is an exceptionally sensitive body part for tactile perception;
4) It's users were taught the method intensity over several years.

The specific actions, included in synthetic Tadoma are:

1) Upper lip in - out movement (UIO)
2) Lower lip in - out movement (LIO)
3) Lower lip up - down movement (LUD)
4) Jaw up - down movement (JUD)
5) Laryngeal vibration
6) Oral airflow.

The present study is aimed at examining the extent to which the face is in fact 'rich' multi-dimensional tactile display. The authors have evaluated the performance, using the four movement channels: UIO, LIO, LUD, and JUD. All of these dimensions were studied separately and jointly with respect to information transmission, using elementary static, nonspeech stimuli. In subsequent research, the authors tend to include vibration and airflow, but also to examine rates

of Information transmission using dynamic, nonspeech stimuli. Assessment of information transmission was carried out in two steps. First, discrimination experiments were conducted to investigate the basic resolution of the human tactile sense with respect to the four movements, UIO, LIO, LUD, and JUD. Identification experiments were then performed to determine how much information could be perceived through the movement systems. All experimental runs started with an informal training period. Discrimination experiments showed that the just noticeable difference associated with each movement is about a percentage of the reference displacement. In general, both the discrimination and identification results appear unexceptional and hence, the reception of facial movement information by itself, does not account for the extraordinary success of the Tadoma method.

Weisenberger, J.M. (1989): Evaluation of the Siemens Mini-fonation vibratactile aid. JSHR, Vol.32, Page 27-32.

The Siemens Hearing Instruments,Minofonator, a single channel, wrist worn vibrotactile aid, was evaluated in a laboratory setting with hearing-impaired adults. In the present study, the ability of the Minifonator to aid detection of sound was measured in a standard sound field

audiometric setting with hearing-impaired adults. These subjects were asked to identify a set of 20 environmental sounds recorded on a disk and presented through a computer. A set of 30, one and two syllable words was then presented to determine the ability of the device to transmit syllable rhythm and stress patterns. In conjunction with lipreading, 20 standard sentences were presented to evaluate the usefulness of the device to lipreading In a sentence identification task. The issue of whether training with the minifonator would improve performance, was addressed by selecting the environmental sounds and syllable rhythm and stress subtects and training two subjects with these items over a several week period.

The minifonator was then evaluated using listening tasks requiring increasingly complex analysis of the acoustic stimulus, allowing assessment of it's potential benefit to users in a number of listening situations. The results indicated that the minifomator can provide sufficient Information for users to detect the presence of sounds across a fairly broad frequency range and for sounds with primarily high frequency spectra, might actually yield better detectability than many hearing aids.

It has been found that performance of such tasks can improve with practice. Although, single-channel tactile aids probably do not provide a large amount of firm structure spectral or temporal information, the fact that the subjects were able to identify the words in the syllable rhythm and stress task at above-chance levels suggests that some degree of fine structure information is being transmitted. To obtain a more complete idea of the type and degree of benefit that can be provided by a single-channel tactile device such as the minifonator, further work is necessary in training users to integrate the information from the device with visual cues. In addition, the performance of a device with single word stimuli is not always an accurate predictor of performance with connected speech, and thus an evaluation of the minifonator in connected speech tasks should yield results that would be more predictive of it's benefit in real-world situations. It is concluded that minifonator have potential benefit for profoundly impaired persons who do not benefit from conventional acoustic amplification. It is possible that a carefully developed, comprehensive training program that employed graduated exposure to tasks requiring increasing finer analysis of acoustic waveform, might lead to extremely good performance with such devices.

Welsenberger, J.M., and Russel, A.F. (1989): Comparison of two single channel vibrotactile aids for the hearing-impaired. JSHR, 32, Page 83-92.

In the present study, two commercially available single-channel vibrotactile aids were compared using the same subjects, performing a variety of tasks, including sound detection, environmental sound identification, syllable rhythm, stress categorization and speech sound recognition, to determine the type and degree of benefit, provided by each device. One device is the mini vibrator three (an amplitude modulated device) and the other is Siemens minifonator which provides an amplitude modulated broad-band signal. A total of six subjects, between 18 and 22 years participated in the study. Several tasks were performed by the subjects, like sound detection, environmental identification task, syllable rhythm and stress categorization, vowel recognition and consonant recognition. One some tasks (sound detection, environmental sound identification, syllable rhythm and stress categorization information about the envelope of the stimulus was expected to be sufficient for good performance. On others (speech sound recognition) additional information about the spectral fine structure of the signal spectrum was

anticipated to be required for good performance. Results indicated that the subjects performed comparably with both devices on all tasks, suggesting that they did not make use of the spectral information, available in the more complex signal.

In this experiment, tasks in which knowledge of the fine structure of the waveform is required, such as vowel and consonant discrimination, appear to exceed the capabilities of such devices. Minlvibrator yielded higher levels of performance, than the minlfomator, because of strong vibratory signal.

Performance on the vowel and consonant recognition task, in which spectral cues would have been useful was not better with minifonator because of the changing temporal characteristics of the signal presented by the minifomator, made it even more difficult for subjects to monitor changes in frequency than the frequency resolution of the system might suggest. However, further data are necessary to detemine the generalizability of such training to other tasks.

Weisenberger, J. (1989): Tactile aids for speech perception and production by hearing-impaired people. The Volta Review, Vol.91, Page. 79-100.

In this study, a number of perceptual tasks have been evaluated raging from simple detection of a stimulus to tracking connected speech. Results suggest that tactile aids particularly those that use a number of tactile transducers to convey information about the spectral component of the speech signal can significantly enhance speech perception. The authors also evaluated the effects of tactile devices on speech production, finding that profoundly hearing-impaired children's speech can be improved through multi-channel experience, using a multi-channel tactile aid.

Rebecia E Eitens, Kimbrough, D.O., and Kathleen, V. (1989): Speech and language progress of hearing-impaired children in a systematic training program, using tactual vocoders. The Volta Review, Vol.91, Page 127-138.

To evaluate the effect of a model training program, using tactual vocoders, a comparison was made between speech production gains made by hearing-impaired children in the tactual speech project (TSP) and those, made by a group of hearing-impaired children from traditional public school

programs. In the course of about a year, 11 children in the TSP showed gains in syllable inventories and pronunciation of vocabulary items. Comparable gains were not made by a group of 15 children similar to the TSP group in hearing loss, intelligence, socio-economic status, and language background. Another group of TSP children was evaluated for grammatical development (in speech) with the GAEL-P (Grammatical Analysis of Elicited Language - Presentence Level). As predicted based on the severity of hearing loss, secondary handicaps, ethnicity, and socio-economic status, the TSP children started the year with low percentile rankings on the test, when compared to the normed group. However, in 5 months, the group gained dramatically against the norms. Gram atical development of 3 hearing-impaired children (with no other handicapping conditions) who had been in the TSP for 3 years was assessed with the GAEL-S (GAEL simple sentence level). These children ranked above the 80th percentile, although their home language was Spanish and each had more severe hearing loss, than did the hearing-impaired group on which the test norms were based.

The TSP children progress at a rate that makes real speech communication possible for them in classroon settings. Because this study is based on comparisons across programs,

it is not possible to determine the extent of the contribution of the tactile devices, as opposed to contributions of other program factors, on gains in speech production and and perception. It can be concluded that a systematic training program, incorporating artificial hearing devices can provide practical and extensive support for speech production, and language development in young hearing-impaired children. However, in both studies, it is important to keep in mind that a variety of differences between the TSP and other programs may contribute to differences in outcome. While tactual vocoders may play an important role in the TSP, one cannot rule out the possibility that other program factors have contributed to the relative performance of children in the TSP and elsewhere.

Charlotte, M.R., Nathaniel, I.D., Lorraine, A.D., William, M.R., and Ken, w.G. (1989): Research on tactual communication of speech: Ideas, issues and findings. The Volta Review, Vol.91, Page 65-78.

In this paper, the authors present an overview of current research findings in the field of tactual communication of speech. They consider some implications of these findings for future research and speculate about future

research trends in the development of tactual aids. The first section of the chapter is concerned with methods of communication intended for the tactual sense alone. The second section considers issues, related to tactual input as a supplement to speech reading. The last section is a discussion of issues, related to developing a new generation of synthetic tactual aids and to the roles such aids could play in treating people with profound hearing loss.

The summary of the current state of research in tactual communication of speech leads the authors to conclude that there are no fundamental scientific obstacles to achieving much improved speech reception for individuals with profound hearing losses.

Keeping in mind, the tactile aids of the future, the authors say that a major goal in developing synthetic tactile devices is to create aids that lead to speech reception performance comparable to (or better than) that demonstrated for natural methods of tactual communication. The artificial encoding and display schemes studied in the past, clearly donot tap the full potential of the tactual sense for receiving information at continuous speech rates. Recent discussions of the role of tactual aids in the clinical treatment of individuals with profound auditory impairment

have focussed on comparisons with cochlear implants. Information comparing relative performance, clinical effectiveness, cost and risk is essential to rational decision making by potential users of cochlear Implants or factual aids as well as by clinicians and those concerned with allocation of the research resources.

Consideration of the role of tactual aids only in relation to cochlear implants, however do not address several other issues with major implications for the future clinical use of tactual aids. One issue involves the population of people with profound auditory impairment who rely solely on manual, as opposed to oral, methods of communication. Some individuals may have no interest on speech reception, but they may be interested in obtaining nonspeech acoustical signals. Clearly, tactual aids can be highly effective in providing this type of information. A second issue involves the population cf individuals for whom treatment by cochlear implantation is not a reasonable possibility because of funds etc. In such cases, tactile aids may play an important role in the worldwide treatment of profound hearing-impairment.

Clayton, L., and Van Doren (1990): The effects of a surround on vibrotactile threshold: Evidence for spatial and temporal independence in the non-Pacinian I (NPI) Channel. JASA, Vol.87, No.6, Page 2655-2661.

The purpose of the present study was to measure vibrotactile thresholds at low frequencies on glabrous and hairy skin, using a circular contactor with and without a surround, in order to test the hypothesis that spatial and temporal tuning are independent, and to reconcile the conflicting results from earlier Investigations.

Five subjects, aged 20 to 58 years, participated in the study. Tactile detection thresholds were measured at two locations: The thenar eminence of the right hand and the right volar forearm, approximately midway between the wrist and elbow. Stimuli were applied via a 0.72 cm^2 circular contactor, with and without the right surround. At low frequencies, below about 40 Hz, the thresholds were higher without the surround than with the surround. However, in contrast to earlier reports, the shape of the threshold function was the same with and without the surround, suggesting that the temporal and spatial tuning characteristics of the ron-Pacinian I (NPI) channel are independent.

The results of the present study supported the hypothesis that the spatial and temporal tuning characteristics

of the NPI channel are independent. That is, at temporal frequencies below about 40 Hz, the shape of the temporal tuning curve did not change with changes in the spatial configuration of the stimulus - specially, the presence or absence of a rigid surround.

Silvio, P.E. et al. (1990): Speech reading sentences with single-channel vibrotactile presentation of voice fundamental frequency. JASA, Vol.88, No.3, Page 1274-1285.

The main goal of this study was to investigate the efficacy of 4 vibrotactile speech-reading supplements. Three supplements provided single-channel encodings of Fo. Two encodings involved scaling and shifting glottal pulses to pulse rate ranges suited to tactual sensing capabilities; the third transformed Fo to differential amplitude of two fixed frequency sinewaves. The fourth supplement added to one of the Fo encodings, a second vibrator indicating the high frequency speech energy. A second goal was to develop improved methods for experimental control. Therefore, a second corpus was recorded on video disc using two talkers whose speech was captured by video, microphone and electroglottograph. Other experimental control issues, 10 included use of visual-alone control subjects, a multiple base line single-subject design replicated for each of 15 normal hearing

subjects, sentence and syllable pre- and post-tests balanced for difficulty and a speech-reading screening test for subject selection. Across 17 hours of treatment and 5 hours of visual-alone baseline testing, each subject performed open-set sentence identification. Covariance analyses showed that the single channel supplements provided a small but significant benefit, whereas the two-channel supplement was not effective.

All subjects improved in visual-alone speech-reading and maintained Individual differences across the experiment. Vibrotactlle benefit did not depend on speech-reading ability Experiments of results for differences among supplements failed to provide evidence that any one of the single-channel transformations was significantly more effective than the others. In this study, it is possible that, by employing normally hearing subjects, estimates of benefit are obtained less efficiently and may ultimately be less accurate than might be achieved with proficient deaf speech-reachers. As long as speech-reading continues to improve, and vlbrotactile learning progresses slowly, it will remain difficult to estimatenaximum benefit with these supplements. Accurate estimates of benefit may require study of long term users of the tactile supplement. Ironically, development of wearable vibrotactlle devices, has, for the most part

awaited definitive estimates of benefit from laboratory experiments. When hearing subjects are employed in sensory aids research, it is necessary to control for their learning not only the vibrotactile signal, but also the visual speech stimulus.

Joseph, I.A. et al. (1990): Speech feature recognition by profoundly hearing-impaired children, using a multiple-channel electrotactile speech processor and aided residual hearing. JASA, Vol.88, No.3, Page 1260-1273.

The present study forms a continuing evaluation of a multiple channel electrotactile aid, the tickle-talker. Additional objectives of this study were (l) to determine whether the introduction of direct training was associated with improvements in the ability of the children to utilize the speech information, provided by the tactile aid, (2) to compare performance levels on a series of speech feature tests, during "training" and "post-training" phases and 3) to determine whether training a particular speech feature improved the perception of features that had not been trained or of the trained feature in an untrained context. Seven children berween 7 and 11 years of age, took part in the study. The subjects were tested, after one year of training.

The electrotactile aid, used in this study was able to provide useful segmental vowel and consonant speech information that was accessible to profoundly hearing—impaired children. In all the tests, it was shown that the children were able to perceive this information more effectively when the tactile aid was worn, as compared to the aided hearing condition. It was possible to show that direct intervention, in the form of training, was an important factor in the successful perception of tactile information, and that perceptual skills, acquired during training were retained when training was removed. Actually, training was given for perception of vowel duration and place, the fricative /s/ and manner of articulation distinctions. Speech feature recognition tests were conducted in the tactile plus aided hearing (TA), tactile (T) and auditory conditions (A). Test scores in the training and post-training and post training phases were significantly greater than in the pretraining phase, suggesting that the training provided, was responsible for the improvement in feature perception. Statistical analyses demonstrated a significant interaction between the main effects of condition and phase, suggesting that training improved perception in the TA and A conditions, but not in the A condition. Recognition of trained feature improved for trained as well as for untrained

words. There were many advantages of the tactile aid noted. It provided information which was not available from audition. The perception of a particular feature was not restricted to the context in which it was trained, but could be generalized to different contexts.

Linda H. et al. (1990); Training strategies for profoundly hearing-impaired children using the Tactaid-II. The Volta Review, Vol.92, No.6, Page 265-274.

This study presents information on the Tactaid II plus. Including functioning and monitoring of the aid, as well as a training model, witA suggested activities and strategies. A case study is presented to illustrate speech perception performance with the Tactaid II plus, including the realistic and unrealistic performance goals, associated with it. Learning to decode the tactile pattern rarely occurs spontaneously, but requires intensive training in highly structured settings. Thereare a few unrealistic performance expectations with the device.

1) To expect the child to identify warning signals in the environment.
2) It cannot be used to performan open set speech recognition tasks.

3) The child will evidence spontaneous identification of spoken language in unstructured situation.

It can be concluded that, nevertheless an instrument, such as the Tactaid-II plus can serve as an important sensory aid to profoundly hearing-impaired children who receive negligible benefit from hearing aids.

George, A.G. et al. (1990); Vibrotactile Intensity discrimination measured by three methods. JASA, Vol.87, No.l, Page 330-338.

The purpose of this study was to measure the DL for vibrotactile intensity discrimination over a wide range of stimulation, (from 4-40 dB SL). The authors thought that use of such a wide range of vibration amplitudes would afford a stronger test of Weber's law that was possible in earlier studies in Which amplitude range was relatively small. Both sinusoidal and noise stimuli was used to determine, whether, as in hearing, the "hear miss" to Weber's law is observed for sinusoids while Weber's law is observed for noise. The difference threshold for detection of changes in vibration amplitude was measured as a function of Intensity and frequency of stimuli, delivered through a 2.9 cm contactor to the thenar eminence. Stimuli were either

duclng the lower DLs. If priming plays a role in determining the vibrotactile DL, it may be related to the duration of the pedestal and perhaps to the duration of the amplitude increment. Further research should be planned to investigate this problem. Another possible advantage of the continuous, pedestal method is that it makes little demand on memory.

The significance of the results presented here, lies In the fact that, regardless of the channel excited, the DL functions are the same.

Clayton, L.v., George, A.G., and Ronald, T.V. (1990): Vibrotactile temporal gap detection as a function of age. JASA, Vol.87, No.5, Page 2201-2206.

In this article, the authors measured the ability to the subjects to detect temporal gaps between bursts of sinusoids and bursts of band limited noise to evaluate the phenomenon of tactile "sensory persistence" in older persons. Vibratory stimuli were delivered to the right thenar eminence of 27 subjects, ranging in age from 8-75 years. The subject's task was to detect the presence of a silent interval or "gap" between flanking 350 msec, vibrotactile stimuli. The gap detection threshold expressed as amplitude of vibration, relative to the absolute detection

threshold, decreased as the gap duration increased and was higher for gap* in noise, than the gaps in sinusoids. The thresholds for detecting short gaps increased for noise stimuli but not for sinusoidal stimuli.

Furthermore, the gap detection threshold recovered more rapidly in older subjects for noise, rapidly appears that the effects of age on gap detection cannot be due to a simple increase in sensory persistence, but may be due to multiple processes. Effects of rise-fall times and stimulus duration were not investigated In the present study.

Gunilla, O. et al. (1990): Tactiling; A usable support system for speech reading? STL-OPSR, 2-3 Page. 69-77.

The purpose of this study was to find out whether a deafened adult can take advantages of the added information, given by vibrational and motional patterns, he picks up, by placing his hands on a speaker' s throat and shoulder and how valuable that is, as a support system for speech reading. Eight deafened adults were studied, with the help of pre-test post-test control group design. The experimental and control groups took speech reading classes together. The experimental group received additional Individual training In tactiling during six lessons. Both the groups were tested, before and after training, first by a familiar person and

after a fortnight, by an unfamiliar person. A 3-way ANOVA was used. It was shown that tactillng was better than speech reading and the results from the test, given by the familiar speaker are better than the unfamiliar speaker. The main effect of tactiling over speech-reading suggests that the method is worth pursing as a support system for speech reading. This study did not reveal any main effect of training. The method, eventhough a good supplement to speech reading, entails some social restraints.

Weisenberger, J.M. et al. (1991): Evaluation of a principal components tactile aid for the hearing-impaired. JASA Vol.90, No.4, Page-I, Page 1944-1957.

Tha present study describes the development, modification and evaluation a principal components based tactile aid for speech perception by the hearing-impaired. In this device, the first two principal components of an input . speech signal were displayed on two dimensional arrays of vibrators, contacting either the finger tip of the forearm. Initial testing of the device with closed set recorded speech tokens showed fair recognition performance, reaching 57% for three consonants and 56% for four vowels.

Modification of the processor algorithm designed to improve vowel recognlzability resulted in higher levels of

performance (66% for 8 vowels). A real time prototype was constructed. Implementing the raised algorithm. Live voice testing was conducted with mix normal hearing subjects, three of whom had previous training with the Queen* s University Vocoder, a multi-channel tactile vocoder that has shown promising results. Performance of these trained subjects for both single item and connected speech tasks were excellent equalling levels obtained. These results suggested that a principal components design may be a promising alternative to a vocoder strategy for a tactile aid. Results of the naive subjects did not reach the levels, attained by the trained subjects, a finding partially attributed to the short training period.

Principal component analysis (a statistical data reduc=-tion technique), used in this study, to eliminate redundant information, is quite promising as a speech coding strategy in auditory perceptual studies. Principal component analysis uses across frequency correlation in spectral energy in a waveform to produce small set of independent parameters. These parameters or principal components, contain Information about the overall spectral shape of the waveform, rather than only it's spectral peaks. Although,

a conclusive determination of the advantages of bilateral versus unilateral displays of speech Information was not possible in the present study, the fact that the advantage obtained with Bilateral display was small and the complexity of a single display principal components representtion may not premit processing of additional information even somewhat redundant information.

Aglfora, o*, oa<i aiaberg* A, (1991): Speech BorefDf^oq abllltioa of 7)jti%::t3, uoinn cochlea* ^npfaato. vlbae* tactile aloe gnc 'i;'i:i;::! oido. ^rL-ATOR, 2-31/1991, P37O 29-40,

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% toot battery woo constructed that consiatc^ of scg-nv-rital m^ 3upr%#egmc:itnl tasks aid apooch trqcki:;v, &wo preaentatlon nodalltiee wore u#&8, vloion o ly one visual iaplGmGntatlon aupploaented with aaaistlve device* Deafened

adults, subjects with profound post-lingual hearing loss, and normally hearing subjects artificially deafened participated in this study. The results showed that single channel tactile aids did not give sufficient support during speech reading and that the use of a hearing aid by listeners with some residual hearing often provided more information than a cochlear implants. However, a group of hearing aid users got very limited benefit from their aids. They might, therefore be candidates for implantation. Criteria for patient selection can, however, not be based on pure tone audiometry. It is recognized that the comparison between the results obtained by different teams or devices in tests with post-lingually deaf is difficult. To get a uniform selection of patients is more or less impossible. The performance among individuals showed often great variations, not only as a result of what they feel with their device, but as a result of their varying ability to lipread or make use of small linguistic and paralinguistic cues. A standardized test material does not exist in any language and the phonological characteristics from one language to another, make the inter-lingual comparisons, complicated. It can be

concluded that the result* of the tactile group and poor hearing aid group are very similar, where improvement In the situation, llpreading plus aid are shown, compered to the situation without aid.

CONCLUSION

Like the two sides of a coin, the tactile aids have got their own advantages and disadvantages. Several general statements can be made about the usefulness of tactile devices to enhance the perception of speech and other acoustical stimuli. Single channel tactile aids can provide appreciable benefits for profoundly hearing-imp airedpeople- particularly, in the detection of sound and in tasks that rely on envelope based cues for perfor-mance. Some benefits in connected speech tracking have also been observed when performance with single-channel devices has been compared with that of speech reading alone, but these benefits are not large. Second, adding a second-channel can improve the performance over a single-channel device in certain situations, such as, in detecting the high frequency components of the speech signals. A second channel may also yield improvement in the ability to perceive connected speech. The number of channels required for optimal performance is still not clear. It does appear to be true that not all tactile aids can be expected to show comparable performance. It is also apparent that performance on single item tasks has little relation to performance with converted speech. Finally, higher levels of performance can occur, when multichannel tactile aids are used in conjunction with speech reading.

The disorders of integration that existed may be visual, auditory, tactile, vestibular or kinesthetic. It was found that those who received sensory motor training showed/greater gains in auditory language and reading skills than those who spent extra time in classroom, receiving special auditory and language training. A tactile device can potentially help the profoundly deaf in everyday communication. Although, these demonstrators of the benefits of tactual aids are promising, there is little information to suggest how to improve the performance of tactual aids. This is due, in part, to the dearth of research in sensory integration across the three important modalities of vision, hearing and taction.

The user of the aid has the advantage of developing an improved awareness of the rhythm, pitch and intonation. Identification of speech sounds should also improve and depending on the vlbrotactile device selected, the user will be able to discriminate/between voiced and voiceless phonemes by location of the stimulus alone. The improvement in these skills as will contribute to improved speech and lipreading skills, improvement in speech training skills and the child's own speech production.

The manner features of speech (nasality, voicing and fricative properties) are difficult to lipread, because their production is difficult to see. However, the manner features are all well below 1 KHz are easy to feel.

Tactile aids are thus useful adjuncts to lipreading.

In contrast, considering speech from a spectral view point, the tactile aid cannot be used to comprehend speech to the extent that the second and third formants are required.

Electrocutaneous stimulation has several advantages. Electrodes used, being small and contact, the power consumption being low and electrode life span being long, electrocutaneous stimulation enables the use of a broad spectrum of stimulus parameters, as compared to vibrotactile stimulation.

To summarize, the current status of the field are as follows:

1) The tactual sense is capable of receiving continuous speech at nearly zero error rates.
2) Subjects are capable of integrating a relatively impoverished tactual signal with visual speech reading to achieve essentially normal speech reception performance.

3) Limitations of the speech reception performance obtained with current tactual aids are due primarily to inadequacies in the design of the aids and/or in the training received with the aids.
4) There are no fundamental scientific obstacles to eliminating these inadequacies and achieving much improved speech reception for individual with profound hearing-impairment.

Considerably less work has focussed the potential of tactile devices to benefit the production of speech by the hearing-impaired. Number of studies have connected anecdotally on improvement in speech production, paired by single channel tactile aids. However, experimental evaluation of such improvement is somewhat rare.

Overall, the data from the laboratories indicate that the aids can be of measurable benefit for both the perception and production of speech. Continued research into how the best approach to development of optimal, physical device parameters and training procedures should provide further information about the benefits, that can be derived from using tactile aids.

Discussing the sensory communication channels, Geldard says- if one attack is to force a receptor system to perform in an unnatural way by trying to adjust it to the world's hardware, the other involes asking how the world and the things in it might be modified to get the most, out of the senses.

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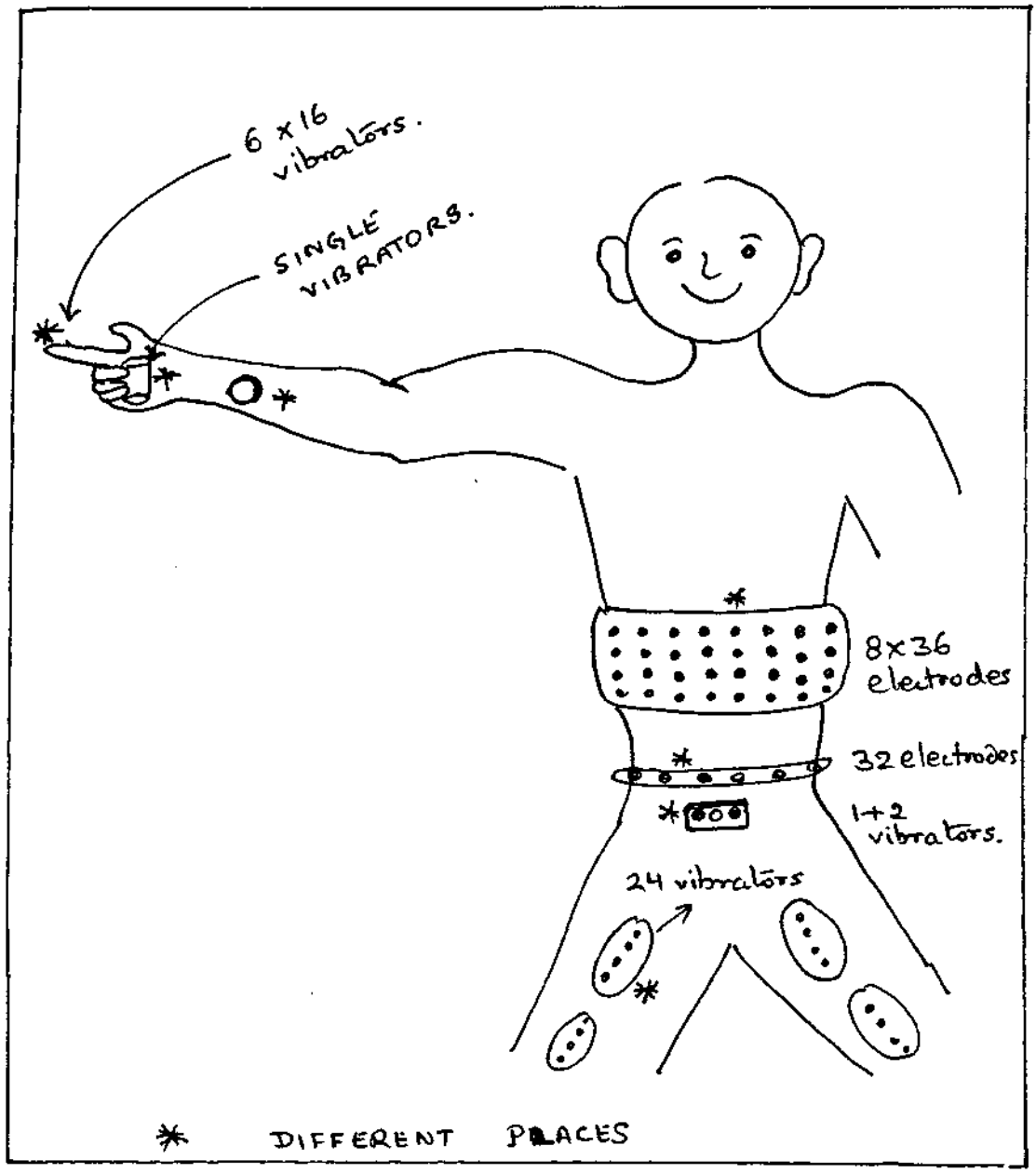
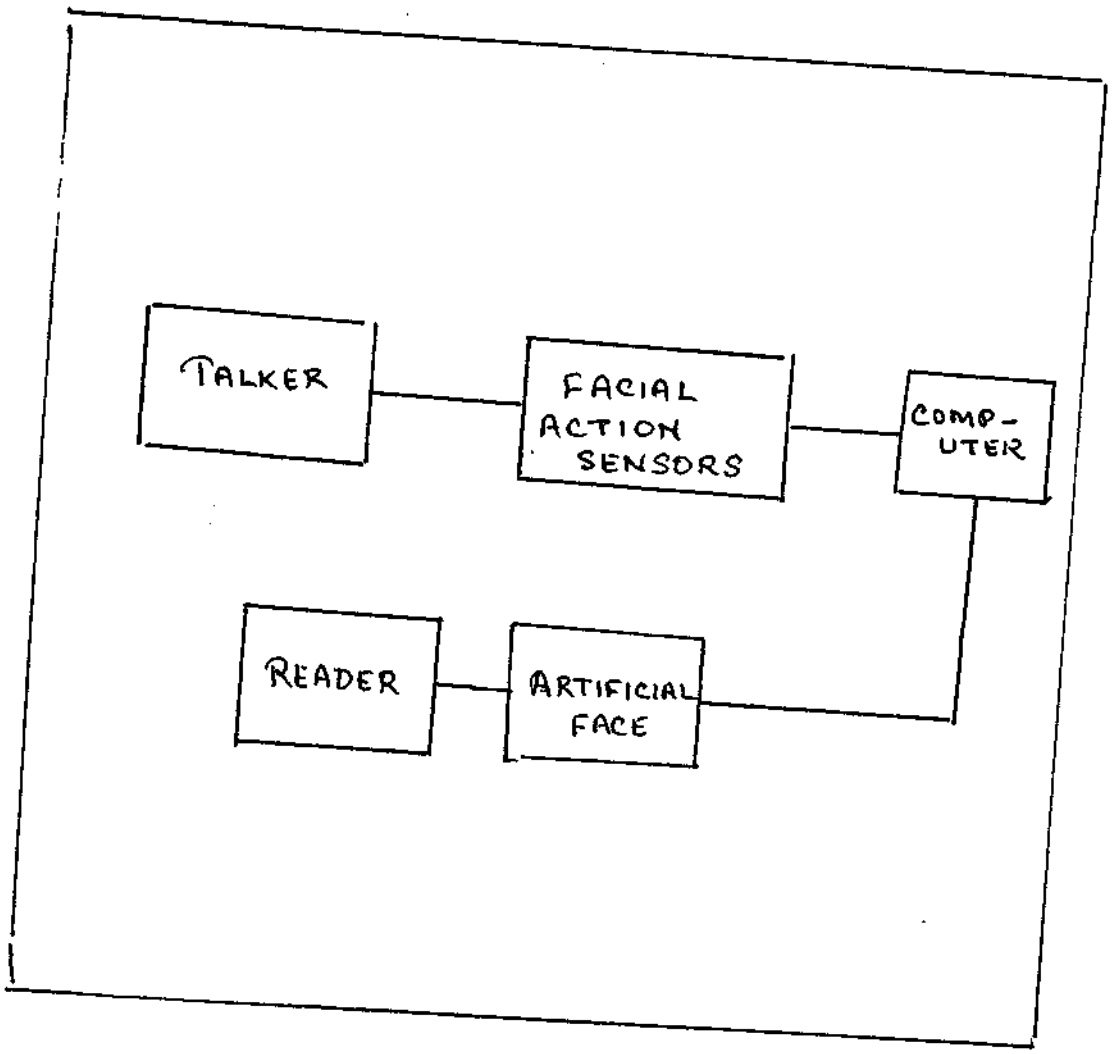


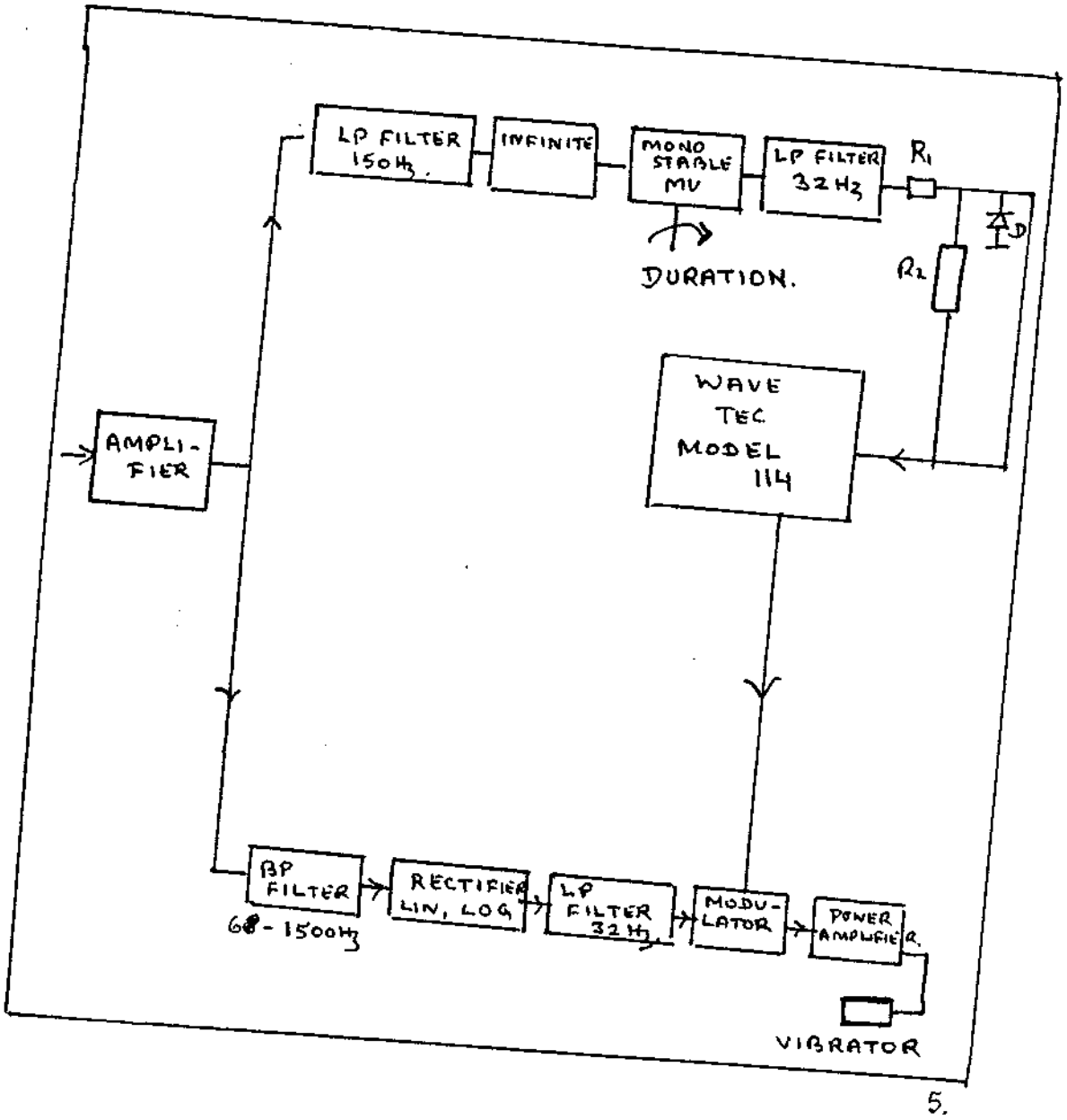
1.

DIFFERENT TACTILE SPEECH COMMUNICATION AIDS WITH THEIR RESPECTIVE PLACES OF STIMULATION.



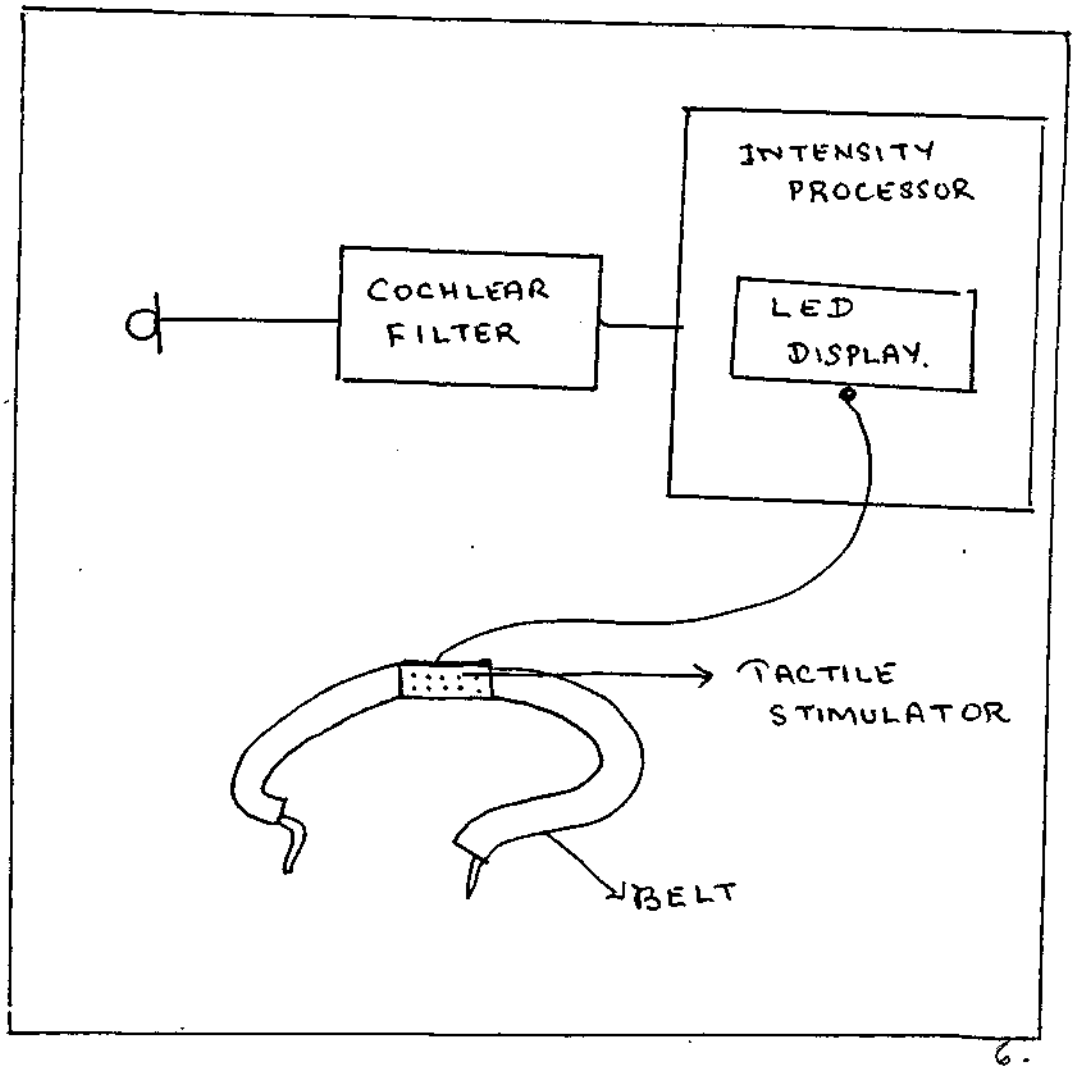
2.

SCHEMATIC BLOCK DIAGRAM OF THE SYNTHETIC TADOMA SYSTEM.

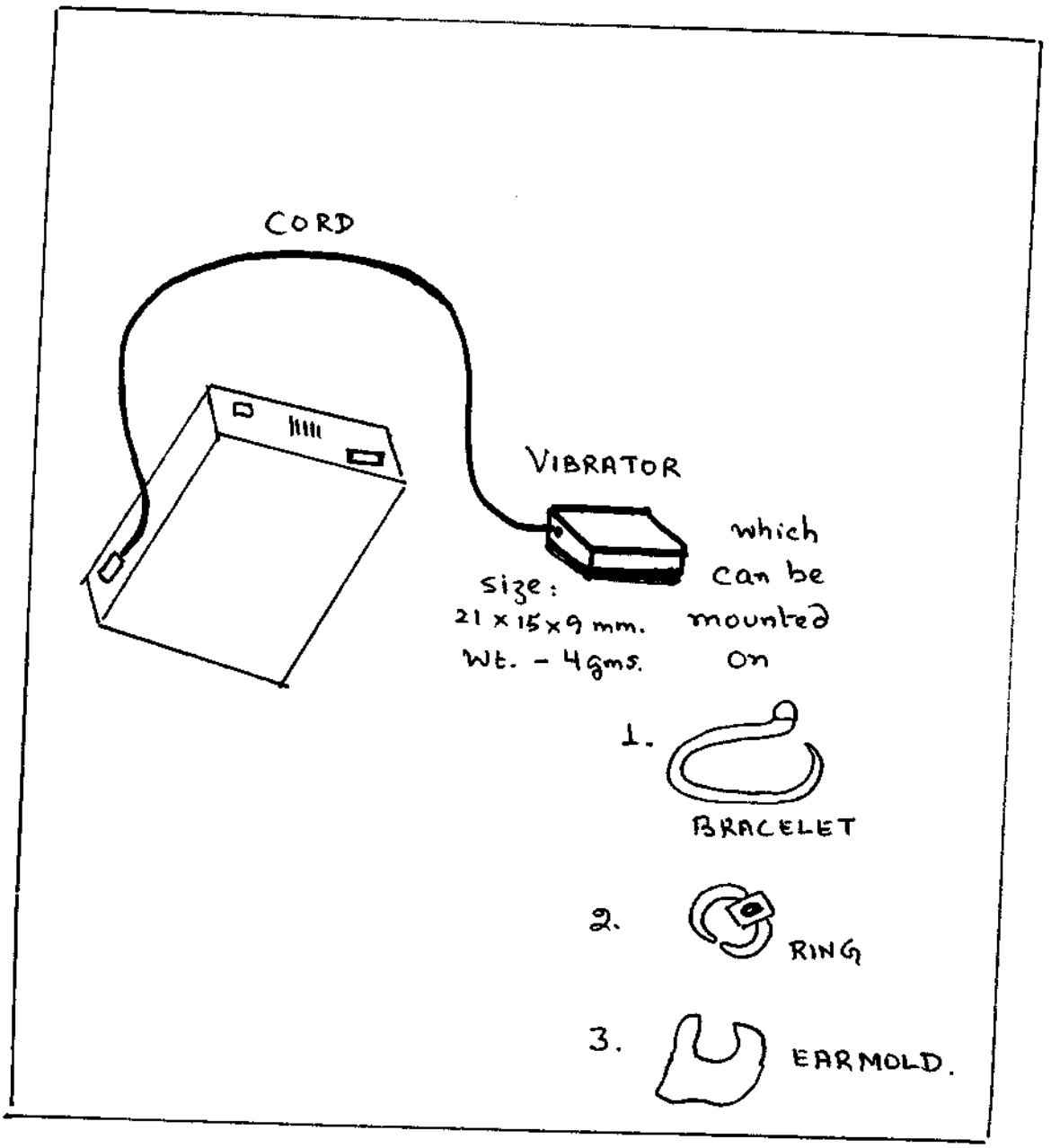


A VIBROTACTILE AID BY (GEOOF PLANT ETAL.)

'An Experimental Equipment used in the study'.



MULTIPOINT ELECTROTACTILE SPEECH AID (MESA).



A TACTUAL HEARING AID FOR THE DEAF (K.E. Spens & G. Plant).

Test Feature	Unaided Speechreading	Aided speech-reading.
- Overall.	57.	81.
- Voicing	68	85
Manner of Articulation.		
- Overall	84	95
- Stops	89	95
- Sibilants	85	97.
Nasals	53	79
Place of Articulation.		
- Overall	100	100
- Bilabials	100	100
- Labiodentals.	100	100
- Alveolars	100	100
- Velars.	99	100

USING A VIBROTACTILE AID. 7.

Percentage correct scores obtained by a profoundly hearing-impaired subject for the unaided & aided speech-reading of 12 consonants in an /aCa/ syllable.