A REVIEW ON LOUDNESS RECRUITMENT

by

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CERTIFICATE

This is to certify that the independent project "A Review on Loudness Recruitment" is the bonafide work in part fulfillment for III semester M.Sc (Speech and Hearing), carrying 50marks, of the student with Register Mo. 10.

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This is to certify that this independent project has been prepared under my supervision and guidance.

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Guide

DECLARATION

This independent project is the result of my own work undertaken under the guidance of Mr. M. V. Vyasamurthy, Lecturer in Audiology, All Indian Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

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CHAPTER-I

INTRODUCTION

Sound as a physical phenomenon, is the legitimate domain of the physicist; as a concept, it comes within the province of the psychologist. Many clinicians would gladly surrender all claims of these territories but for that fact that modern Otology and Audiology have brought us right up to the frontiers into a "No Man's Land" where all is vague and ill defined. The phenomenon of Loudness Recruitment lies in that "No Man's Land" and it is a remarkable fact that although this phenomenon has been universally recognized as the prime diagnostic significance, no clear explanation of its mechanism has so far been put-forth.

The phenomenon of Recruitment was first reported by Edmund Prince Flower in 1928 before the section of Otology of the New York Academy of Medicine.

1.1 Definitions: A proper definition for Recruitment of Loudness should include not only a description of what it appears to be but also what appears to be its genesis.

One of the best definitions of Loudness Recruitment is that of Hirsh, Palva and Goodman who describe it as "a more than normal increase in subjective loudness for a given increase in physical intensity". A patient with recruitment in spite of impairment at threshold hears loud sounds with a sensation of loudness equal or nearly equal to the loudness with which a normal ear would perceive them.

According to fowler (1965), Loudness Recruitment is the greater change (or the difference) in the increment of loudness, in relation to stimulus increase observed in ears with partial neural loss of hearing as compared with normal ears ore ears with only impedance lesions.

The shorter definitions of Loudness Recruitment include:

1. <u>For the Clinical Otologist:</u> A measurable increased increment of loudness encountered only in ears with a partial neural impairment of hearing.
2. <u>For the Psychologist and Acoustic Scientist</u>: An accentuation in the increment (or increase) of subjective loudness in relation to the increase in stimulus. Von Bekesy puts it as 'A change in loudness increase in relation to the stimulus increase'.
3. <u>For a patient who has a Recruitment of loudness:</u> An increased annoyance for loud sounds, especially suddenly introduced loud sounds; a decrease in the range of sound

intensity which is comfortable for hearing.

Thus a patient exhibiting Loudness Recruitment will say ‘Don’t mumble’ or ‘I can not hear your voice, it seems loud enough but I can not understand what you are saying (or rather shouting). This annoyance is occasioned not only by the unexpected loudness but by the disagreeable blurring or fogginess of the very loud sounds, seemingly much more than before there had been a loss of hearing for faint sounds. Of course a very loud sound is always more distorted than a moderately loud sound. But in a recruiting ear it is more disagreeable, and uncomfortable (and even intolerable), it is irritating and therefore may seem louder than it really is.

For teachers of the deaf the phenomenon of Recruitment is not of significance except that 3 following points about it:

1. Full or Partial Recruitment seems to be present in about 2/3 of children is school and classes for the deaf and partially hearing;
2. If anything, children with recruitment tend to hear better than those without it; and
3. Thresholds of discomfort and not lowered due to the presence of recruitment.

1.2 Signs and symptoms in a case of Loudness Recruitment

Although there are available, a wide variety of tests, the detection of recruitment is very often difficult and uncertain. In consequence, therefore, many workers have listed the symptoms of the phenomena which can be used in the clinical situations as a supplement to the more formal tests.

The following phenomena are associated with Loudness Recruitment:

1. A change in the pitch of the tone in the recruiting ear (Fowler 1965).
2. A loss of clarity, a fuzziness of the sound in the recruiting ear (Fowler 1965).
3. High threshold of discrimination for pure tone audiometry. Since the recruiting ear has a smaller difference limen, the margin between hearing and not hearing will be narrow and he thus responds to threshold tests with confidence.
4. Sudden decrease in speech reception capacity. A slight increase in threshold loss will bring about a loss in capacity to hear speech out of all proportion to the increase in deafness (Huizing)

5. Lack of voice control when trying on a hearing aid for the first time (Huizing)
6. Recruitment is associated with tinnitus, diplacusis and vertigo (Mygrind et al)
7. Recruitment is associated with lower threshold of tolerance is low tolerance for loud sounds (Mygrind et al)
8. In some people but not in others with comparable losses of hearing, a lowering (sometimes practically a total loss) in ability to understand articulate speech although it may sound quite loud to the recruiting ear (Fowler 1965).
9. An effect, often a favorable effect, on the ability to locate the point of origin of a sound (Fowler 1965).
10. In some people any or all of these phenomena may differ in degree or quality and even as between the 2 ears of sing person (Fowler 1965).

All of these phenomena, all of these aberrant symptoms, are correlated and in various ways interdependent, if one in present, we should search for all of the others.

An explanation of the symptom would include patient's voice, being near the microphone, is of higher intensity than that of the speaker some feet away and this being so, recruitment may occur for the higher intensity but not for the lower, causing an abnormally large discrepancy between then loudness of the 2 voices. The sudden unexpected loudness of the patient's own voice causes him to lose the normal control he has over his own voice and sometimes may cause a mental blockage which prevents him from speaking at all.

Recruitment of loudness is a symptom importance for diagnosis, medical and surgical treatment, for the prescribing of hearing aids and for a better understanding of how the ear functions. It occurs only with a partial impairment of hearing due to neural lesions whether thse occur in limited areas of the Basilar Membrane or in several or in all frequency areas. It is never found with purely external, middle ear or tubal impedance lesions and of course it can,t occur in totally deaf ears.

When recruitment is present at the threshold of hearing is very definite- there is no uncertainty about it, a sound is either heard or not heard, because the minimal detectable difference in intensity is smaller than in non-recruiting ears.

When recruitment is present the change in the increment of loudness is greatest near the threshold and rapidly diminishes with increases in stimulus. The difference in dB loss between the normal hearing ear and the partially

Deafened recruiting ear diminishes with intensity although the increment of loudness at successive levels above threshold continues greater than that in an average normal hearing opposite ear, or in any ear without a neural lesion.

Since when recruitment is present it requires less than 1 dB above the threshold to hear the sound, it may be said that even at the minimum perceptible threshold recruitment is present and can be measure. According to fowler (   ) recruitment is functioning below threshold as well as above threshold. This means that there is a sub audible increased increment in response in relation to stimulus increase, although as yet we have no means for measuring it.

When a change in increment of loudness is greater than in ears unaffected by neural deafness recruitment is present. The corollary would be the presence of neural deafness in pathognomonic by neural deafness. When there is small impedance deafness (5 to 10dB) coincidental with a neural lesion, recruitment may appear to be incomplete as it obviously always appears to be with marked impedance lesions, it appears to be short, the exact or approximate number of the decibels of the impedance. In other words, no sound, no matter how loud can be perceived as loud as the same intensity sound in an apposite average normal hearing ear, if an impedance lesion is present. This apparent stoppage short of complete recruitment is deceiving since recruitment is purely a sensori-neural phenomena, a neural problem and except as displayed by the Alternate Binaural Loudness Balance has no connection with losses caused by tissue impedance. Since the available loudness range is decreased in the case of impedance lesions the whole remaining available loudness range will allow of less loudness change in the whole range, but will cause no alternation in the increments of recruitment of loudness. In the absence of measurable full or complete recruitment there is some amount of impedance deafness or some neural lesion in the opposite ear, the reference ear employed for ABLB technique. Impedance lesions always appear to limit recruitment. They are surely a cause of so called under or partial recruitment.

In speaking of these thing is must be kept in mind that the ear with recruitment is always (at the time of testing) an ear with lowered hearing and therefore the decibel intensities required for threshold the decibel intensities required for threshold and for sounds above threshold and greater than a casual glance at the audiogram might indicate. If in any average normal-hearing ear the intensity of the sound is increased to 30dB above threshold, its loudness is increased by 1000 times, where as a 30 dB increase in intensity above threshold in an ear with 30 dB hearing loss, provides a sound magnified 10,00,000 times above average normal threshold although this constitutes only a 1,000 times increase for the aear with a 30 dB impedance.

Any sound while present may cause recruitment (i.e. , each masking sounds, even vibratory and non-vibratory tinnitus) and often for a time following termination, a temporary threshold shift. Any of these may be said to cause a temporary neural loss of hearing; all while present diminish the member or hair cells or neural elements immediately available for response.

CHAPTER - II

MECHANISM OF RECRUITMENT

2.1 Recruitment - a fact or an Artifact:

The concept of loudness recruitment which is widely accepted as an abnormal auditory phenomenon is contradicted by many authors. Stevens and Davis (1938) adequately showed that the phenomenon of recruitment is not abnormal. The data shown in the loudness function curve reveals that loudness level of 1000 Hz tone at 40, 70 and 100 dB SPLs is approximately 1, 10 and 100 sones respectively for normal subjects. Therefore, if an individual has a sensori-neural loss of about 40 dB SPL (equal to 1 sone) there will be loudness loss of 1 sone throughout the intensity range. That is, he will perceive a tone of 70 dB SPL at a loudness level of 9 sones and a tone of 100 dB SPL at a level of 99 sones. Thus the difference in the loudness perceived by the normal and the abnormal ears is very small.

In pure sensori-neural loss cases, the basilar membrane will be stimulated by all of the energy reaching the cochlea and not just by the energy corresponding to the sensation level. Thus the loudness of a tone seems to depend on the energy reaching the cochlea and not on the sensation level of the tone within certain limits. Therefore the loudness produced by a tone of 60 dB HL at a normal ear will be equal to the loudness produced by a tone of 60-75 dB HL in an ear with 30 dB of sensori-neural loss.

Previous research findings and a careful perusal of case reports with normal subjects and those with sensori neural hearing loss appear to support the hypothesis that the outcome of the recruitment tests depend on whether the tone decays or not.

If we consider the DL tests for recruitment, just noticeable difference in a function of the intensity level of the tone (Riesz 1928). Even in the case of subjects with sensori-neural loss, it has been found that the jnd is a function of the intensity level of the tone and not of the sensation level (Swisher et al 1966; Luscher 1955). If at a particular level there is tone decay, then the jnd at that level will be larger, indicating no recruitment or partial recruitment as compared with a normal ear.

If we consider the ABLB test given to a case with unilateral sensori-neural hearing loss, it indicates the presence of recruitment if there is no tone decay in the affected ear. Since there is no loss in the intensity of the tone that has reached the cochlea the loudness perceived will be almost equal to that in the normal ear in spite of the reduced auditory acuity. On the other hand, if the tone decays, the subject will need greater intensity levels to compensate for the loss due to the 'decay' of the tone. Hence he may be said to show no recruitment or partial or delayed recruitment.

Similarly in the case of SISI test, SISI scores depend not on the sensation level but on the intensity level reaching the cochlea (Herbert, Young and Weiss, 1969; Young and Herbert 1967). On all cases (normal's, conductive loss cases and sensori-neural loss without tone decay) high SISI scores will be obtained when intensity level of tone reaching the cochlea is about 60 dB SPL, whereas those with retro cochlear type of sensori-neural loss showing high tone decay, fail to detect the 1-dB increments at the same intensity levels.

Jerger and Harford (1960) in their study on simultaneous binaural balance test observed that the subjects with cochlear type of impairment require approximately equal HLs in both ears at point of balance whereas the subjects with retro-cochlear type of impairment greater HL at poorer ear at point of balance.

Dix (1968) has shown that the loudness discomfort level both for normal's and for subjects with 'end organ deafness' was between 90-105 dB in spite of the hearing loss being as much as 80 dB in the end organ deafness group. They also showed that for those with conductive loss of less than 20 dB, LDRs were elevated by the amount of hearing loss.

R. Rangasayee (1975) conducted a study to verify the hypothesis- 'Recruitment is an Artifact'. He carried out 3 experiments. Experiment I was comparison of acoustic stapedial reflex threshold obtained before and after inducing temporary hearing loss (cochlear) in 10 normal hearing subjects, at 1 KHz and 2 KHz. After significant time gap, the procedure was repeated on 4 subjects for text-retest reliability.

In the experiment II, the reflex thresholds at 250, 500, 1 KHz , 2 KHz and 4 KHz of typical moderate sensori-neural hearing loss cases with no tone decay were compared with that of normal reflex thresholds. After significant time gap, the measurements were repeated on 5 subjects for test-retest reliability.

In experiment III, screening ABLB was administered on 4 cases with unilateral high frequency sensori-neural hearing loss. The test was administered at the highest bilateral normal hearing frequency. The hearing level at which a pure tone sounds equally loud in the normal ear, when a reference tone of 80-90 dB HL was fed to the affected ear was determined.

The interaural intensity difference at the point of balance was determined.

The results of the first experiment reveal that the growth of loudness in the temporarily induced (sensori-neural) hearing loss is not abnormal. Observation of the temporary threshold shift and the shift in acoustic reflex threshold shows that the shift in ART is about 10-15 dB, irrespective of the amount of TTS. This constant shift in acoustic reflex threshold irrespective of TTS, is an evidence to show that the growth of loudness in the induced temporary hearing loss is not abnormal.

It is know that the reflex is elicited when a stimulus is perceived at a particular loudness level (Flottorp, diupesland and winter 1971, Brooks 1918; Ewetsen et al 1967; Moller 1961, Thomson 1955). For example, if we consider a subject whose absolute threshold at 1 KHz is 85 dB, in this subject the reflex is elicited when the loudness level is 85 phone or 32 sones. When the subject's ear is fatigued acoustic reflex occurs at 95 dB HL. If the loudness depends on the sensation level, ART should shift by 50 dB, i.e., the shift in ART should correspond to the amount of TTS. This shift in Art which is just 10 dB even though the TTs is about 50 dB is explained on the basis of loudness perceived.

Reflex occurs when the stimulus is perceived at a particular loudness level. In presence of 50 dB TTS, reflex can be expected when the loudness perceived is 85 phons or 32 sones. Using Fletcher's (1953) formula, we know that loudness in sones N=2 (L-40/9) L- loudness level in phons approximately 50 dB loss into the acoustic reflex threshold, after the ear is fatigued, we find that the reflex threshold in the presence of 50 dB TTS, is 95 dB which is equal to 32 sones (threshold=50dB). This clearly shows that the growth of loudness in the temporarily induced hearing loss is not abnormal.

An ear with 60 dB loss incurs a loudness loss, approximately or 4 sones. But for every 9 dB increase above threshold, he perceives half the loudness of the normal's would perceive. The difference between the impaired ear and normal ear will be just 10 dB.

The findings of the experiment II are in agreement with the hypothesis that loudness (Determined by elicitation of reflex) perceived by sensori-neural hearing loss ears without tone decay, is diminished by half the normal loudness (Equivalent to about 10-15 dB loss in intensity). In other words, the difference in the loudness perceived by normal and sensori-neural hearing ear is negligible as diminution by half the normal loudness is just 9 dB loss in terms of intensity.

The findings of the 3rd experiment support the hypothesis that ‘Decruitment is an artifact reflecting simon’s and Dixon’s (1968) hypothesis of ‘Summation Loudness Decrement’ principle to explain Decruitment.

The following conclusion can be drawn from this study:

1. The difference in loudness, experienced by normal ear and the ear with induced hearing loss (cochlear) is negligible.
2. The difference between the ART of moderate (40-70 dB HL) typical sensori-neural hearing loss cases without tone decay and ART of normal ears is less than 10-15 dB.
3. The stapedial reflex thresholds are elevated in sensori-neural hearing loss cases, by approximately 10-15 dB as to compensate the loudness loss resulting from the elevated pure tone thresholds.
4. The growth of loudness in abnormal ears is not abnormal as shown by I and II experiments. So recruitment, a presumed abnormal growth of loudness is an artifact.
5. Decruitment, a presumed abnormal slow growth of loudness is an artifact.

Theories of Loudness Recruitment

There are many theories explained the mechanism of loudness recruitment but none is generally accepted. Some of the important theories are given here.

2.2 Hearing Theory or Occlusion Theory of Loudness Recruitment by Lorente de No.

Harris has quoted Lorente de NO's explanation of recruitment in a discussion of Fowler's paper as follows: "If a number of hair cells in the ear or a number of fibres in the cochlear nerve is missing, the tones will appear to be weaker in intensity when near threshold stimult are used; but if the intensity of the tone is increased, the more strongly activated hair cells or cochlear fibres will be sufficient to saturate, i.e., to excite the limiting intensity of the cochlear fibre or the cells of the cochlear nuclei, so that the cerebral cortex will receive the same number and will perceive the tone delivered to the diseased ear as strongly as the tone delivered to the normal or less affected ear. Since a slightly different pathway is used the sound received may be qualitatively different from the original signal."

Evidence: Some recruitment patients report a change in pitch of the sound.

2.3 Constant Loudness-Loss Theory (Stevens 1938), Stein-berg and Gardner (1937) and Steinberg (1937) first attempted an explanation of recruitment in psychological terms, using the ‘loudness’ as contained in the classic paper of Fletcher and Munson (1933). Suppose an ear to be 20 dB deaf for a certain frequency, a tone at threshold for this particular ear amounts to loudness of about 100 units for the normal ear. But suppose the tone were increased 20 dB over the deafened threshold, a tone of this intensity amounts to about 1000 loudness units for the normal ear. A further increase of 20dB intensity produced 4500 loudness units for the normal ear and so on. It is easily seen that because of the nature of the relationship between sensation level and loudness, an ear with a type of deafness resulting in a constant loudness loss would tend to overcome this handicap at high intensities where the percent loudness loss could be unnoticeable (Example : at 40 dB SL percent loudness loss is only 2.0).

2.4 Fiber loss Theory: Steingberg (1935) likewise suggested the loudness matching of different frequencies as a clinical test. His explanation of loudness of recruitment was that if a few nerve fibres were defective this would have a smaller effect as the stimulus intensity increased. The explanation makes the assumption that loudness is some function of number of active fibres.

Dix et al gave a neurological explanation for the lack of in some nerve deaf patients, an explanation depending

Heavily upon, there being a constant fiber survival rate in the lesion. This is know as constant fiber-survival rate theory.

2.5 Duplicity theory: Lurie (1940) explained loudness recruitment in terms of the differential function of the inner hair cells and other hair cells of the organ of corti. He believed that the other cells responded to the sounds of low intensity only and that the inner hair cells responded to intensities of 30 dB and above. If the more sensitive outer hair cells are defective, then the threshold would be raised, but if the sound intensity were raised sufficiently to stimulate the inner hair cells, these would respond normally and a rather sudden increase of loudness might result. This explanation makes the implicit assumption, however, that in the normal ear the outer hair cells no longer contribute significantly to loudness at intensities which stimulate the inner hair cells. In this theory the first attempt is made to explain recruitment in terms of the hair cells rather than auditory fibres. This is called as the Hair Cell Theory by Tumarkin, Dix, Hallpike & Hood.

Evidence: 1. Absence of recruitment in VIII nerve tumors, so they consider recruitment as a symptom of hair cell disorder.

2. Harold. R seen as a result of malfunction of some

part of the end organ of hearing and could not find its presence in cases of VIII nerve disorders or cortical lesions.

Bosatra, A., gives a physiological mechanism for explaining recruitment. According to him an understanding of the recruitment phenomenon is provided by the morphological and functional division of the sensory cells into 2 groups: the external which are more sensitive but are easily damaged by anoxia etc., and the internal which respond to intense stimulus and which are more resistant. The cure of sensation of the external cells starts abruptly but rises much more steeply. This can be assumed by analogy with skin sensation in different areas. It can be admitted that in cases of partial lesion of the sensorial system affective the external cells primarily, a relative loss for weak stimulus but a rise in response for the strong ones is to be expected and this is recruitment. The principle of double sensory system over recruitment and pathological adaptation.

According to Simmons and Dixon (1966) 2 operational mechanisms probably exits for explain recruitment avoiding the stimulus duration and memory. These mechanisms are the

1. Place principle
2. Summation principle

2.6 **Place Principle:** This principle is again explained on the basis of hair cell phenomenon. Loudness information is coded by the cochlea and auditory nerve. According to this principle, nerve fibres excited by outer hair cells require a less intense stimulus than do the fibres excited by inner hair cells (Harris 1953). Traditionally defects in this coding mechanism have been associated with Fowler's recruitment phenomenon (Simmons and Dixon 1966). When the more sensitive outer hair cells (or related strucutes) are damaged, auditory threshold is elevated. When the intensity of a sound is increased and excites undamaged inner hair cells, the resulting loudness sensation eventually equals the undagmed ear. The clearest clinical occurrence of the defect is probably the hearing loss of sound damage. This principle is well established in clinical experience.

2.7 Summation principle: Depends on the total number of nerve fibres excited (Harris 1953). More intense sounds excite a larger area of the cochlea and ultimately more nerve fibres. An important feature of this code is its distribution within the cochlea: as intensity increases, most of the additional energy is distributed towards the basal end; low frequencies spread further than high frequencies. The audio logical consequences of these features have been studied in normal ears and are clinically recognized in masking phenomenon. The consequences of summation

Loudness defects are not well described (Simmons and Dixon 1966).

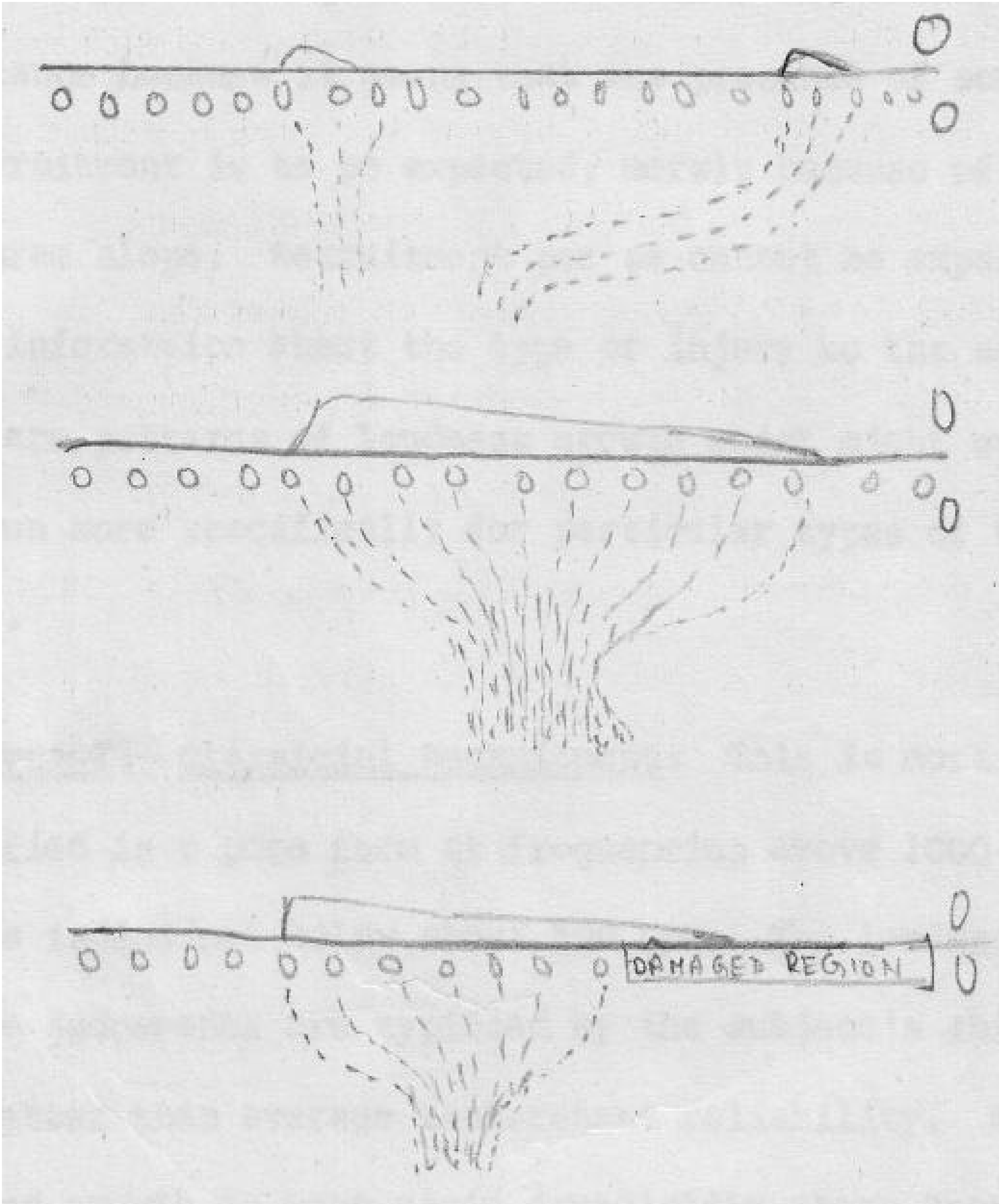


Diagram of sound energy distribution in cochlea, Top: near threshold, the traveling wave excites nerve Pithelial tissue over a small area with low frequencies centered more apically then high frequencies. All frequencies excite about the same number of nerve fibres. Center: As stimulus intensity increases, more and more energy is distributed toward the basal and (high frequency example omitted). Bottom: If this basal cochlear tissue (or nerve fibers) is damaged or destroyed the number of nerve fibers excites will increase at a slower rate than the normal ear (center).

2.8 <u>Summation loudness increments:</u> Summation loudness increments are indeed a built-in characteristic of the ear with apical damage. This conclusion has clinical importance because it means that the presence of some form of recruitment is to be expected, merely because of the audiogram slope. Recruitment per se cannot be expected to yield information about the type of injury to the ear. There are patterns of loudness growth which might eventually be shown more specifically for particular types of tissue damage.

<u>Type - I</u>: **<u>Classical Recruitment:</u>** This is most clearly identified in a pure form of frequencies above 1000 cps and becomes indistinct below about 500cps. The loudness balance judgments are typified by the subject's ability to give better than average text-retest reliability. Rate of loudness growth is most rapid immediately above threshold (early or asymptomatic recruitment). SISI test scores are high, approaching 100% at all test frequencies commonly used. Bekesy type automatic threshold tracking shows both diminished pen excursion and less sensitive thresholds during continuous stimulation. The intensity difference between continuous and interrupted threshold tracking is small (less than 10 dB) and remains constant over a wide range of frequencies above 500 cps.

Type – II: Summation loudness: Defects can't be precisely defined because they depend first of all on cochlear location of the damage with relation to the text tone, not upon a specific tissue abnormality. In Theory, severe damage to the sensory epithelium, its nerve supply, both of these or even perhaps regional structural deformities may produce similar but probably not duplicate effects. The extent to which any of these damages will demonstrate a loudness defect depends upon the sharpness of the demarcation between normal and damaged cochlea, the severity of that damage and the rate at which the traveling wave spreads into or out of the region. Any audiometric features are therefore likely to be most marked near the boundary of such a damaged region and will require summation of excitation over at least several millimeters of the cochlear partition before loudness appears to increase or decrease.

The rate of loudness loss or growth changes slowly immediately above threshold, corresponding to delayed (and sometime incomplete) recruitment during loudness increments. Bekesy audiograms have the same excursion width during threshold tracking with continuous or interrupted tones. Since summation loudness does not depend upon a specific tissue defect, the difference in threshold sensitivity measure by continuous and interrupted stimuli is variable.

Individual loudness balance judgments typically show poor text re-text reliability. Especially in the presence of loudness loss, the patient is willing to accept a greater than average range of comparison intensities are equally loud. It is however more important clinically to recognize this tendency in low frequency hearing losses, particularly when the examiner is naïve or in a hurry to find an intensity any intensity which the subject's range of acceptable loudness matches to recorded as part of the ABLB results (Simmons and Dixon 1966).

2.8 **Summation loudness decrements:** summation loudness defects are not tied inexplicably to dendritic nerve damage but can also be observed in classically recruiting ears. The frequency dependence of summation loudness results from the shape of the cochlear travelling wave is illustrated in the figure. When the damage us severe and abrupt and loudness decrement is more marked.

As yet the suspected correlation between hair cell damage or other cochlear lesion and recruitment has not received support from studies relating behavioral has not received support from studies relative behavioral tests of hearing with changes in the inner ear. Schuknecht's (1953) suggestion that a 50 dB or less hearing loss corresponds to a total or partial loss of outer hair cells and the greater than 50 dB hearing losses involves inner hair cell damage survived for over 15 years. The failure of many experiments to differentiate between inner hair cell and other hair cell losses when reporting damage has made assessment of the above conclusion difficult. Behavioral data from the Ward and Duvall (1971) experiment are in sharp conflict with the conclusion. Schuknecht (1971) has questioned his original assumption on the basis of the subsequent data of Kiang. Because Spoendlin (1966, 1972) presented data indicating that 90-95% of the afferent innervations is from inner hair cells, the number of other hair cells from which electrical recording have been obtained by investigators have been obtained by investigators using micro-electrodes at the level of the cochlear nerve becomes questionable. In view of the variability in lesions found in few definitive behavioral cases reported, differentiation between inner hair cell and outer hair cell function must wait for more experimental results.

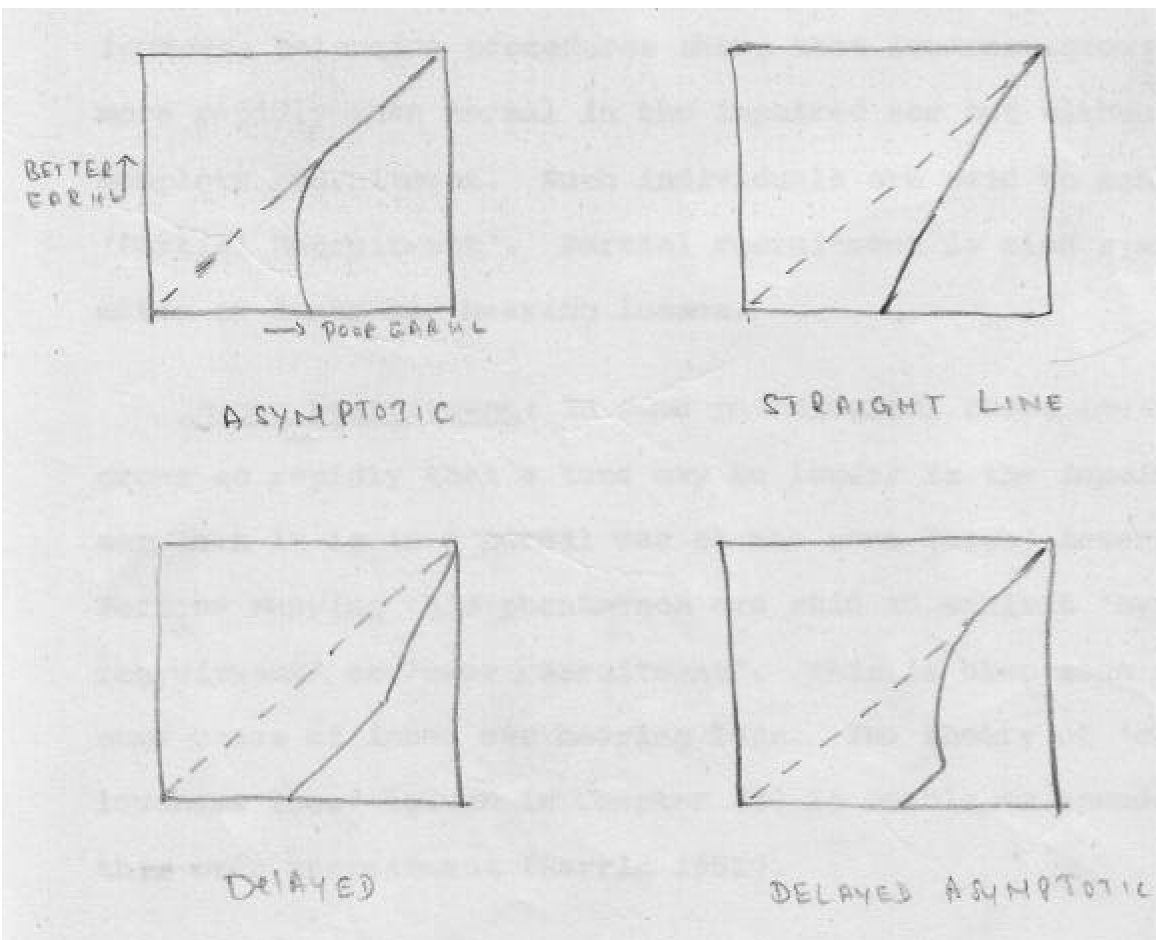
Pride and Coles's data show that if partial recruitment is ignored, complete recruitment is a good indicator of cochlear lesion, while no recruitment is an excellent indicator of neural lesion in a patient with a sensory-neural loss. Also decruitment (loudness reversal) did not occur in any of pride and coles patients with conhlear lesion, only in those with neural lesion.

CHAPTER – III

RECRUITMENT IN DIFFERENT AUDITORY PATHOLOGIES

Classification of Recruitment: Early studies of the recruitment phenomenon led to the classification of growth patterns. That is, Loudness growth functions appear to have several different configurations.

Harris, Haines and Myers (1952) describe four distinct types of loudness growth: 1. Asymptotic, 2. Straight line, 3. Delayed and 4. Delayed Asymptotic



Other investigators differ in regard to the number of different types of recruitment functions. Clinically there appears to be no end to the number of different patterns. Reger (1965) mentioned these patterns. Stevens (1966) postulated that there may be but one function.

Recruitment on the other hand can be classified as:

1) Partial recruitment
2) Hyper recruitment or over recruitment
3) Decruitment
4) Pseudorecruitment

Partial recruitment: Frequently, performance of the loudness balancing procedures shows that loudness grows more rapidly than normal in the impaired ear but without complete recruitment. Such individuals are said to exhibit 'Partial Recruitment'. Partial recruitment is also symptomatic of inner ear hearing losses.

Hyper recruitment: In some pathological cases v grows so rapidly that a tone may be louder in the impaired ear than it is in a normal ear at the same (high) intensity. Persons showing this phenomenon are said to exhibit 'hyper recruitment' or 'over recruitment'. This is also seen in some cases of inner ear hearing loss. The theory of 'constant loudness loss' (given in Chapter II) is unable to account for this over recruitment (Harris 1952).

Decruitment: In some hearing losses, nerve units in the auditory system are missing or damaged and loudness grows more slowly in the impaired ear than it does in a normal ear. To individuals with this problem, even very intense sounds do not produce much loudness.

Pseudo-recruitment: some of the authors have tried to induce recruitment by fatiguing the ear. The fatigued ear may or may not show recruitment, complete recruitment is not the rule, and finally that may of the loudness balance curves show an initial delay before recruitment begins, may be due to slight residual fatigue in the supposedly normal ear.

<u>Recruitment in cochlear pathology:</u> Recruitment the disproportionate increase in loudness as a function of intensity has been demonstrated in all cases of cochlear pathology like-

1. Menier's disease
2. Presbycusis
3. Ototoxicity
4. Sudden hearing loss

Some of the studies about the phenomenon of recruitment in these different pathologies are cited below.

There is evidence that certain clinical entities will tend to show a specific type of loudness growth pattern (Harris 1963); Harris et al 1952; Hickling 1967; Reger 1965; Simmons &Dixon 1996). For instance, it is fairly well agreed that asymptotic growth is seen in persons with hair cell damage (Simmon's and Dixon's place principle), such as that produced by noise. Also, recruitment seen in menier's disease is often described as asymptotic.

Hood (1969) on the other hand claims that recruitment in Menier's disease is linear or straight line. Carver (1972) found straight line recruitment in 13 out of 17 patients with menier's disease, the 4 others were asymptotic.

Simmon and Dixon indicate that loudness growth patterns associated with the summation principle will be delayed or slow and sometime incomplete.

In 1946 De Bruine-Altes published a monograph on recruitment. She concluded from a study that there is no necessity to expect recruitment, either complete or incomplete, neither from all inner ear deafness- nor in all pure conductive deafness free from the phenomenon. Recruitment in prebycusis was absent and might have been absent in explosion trauma and basal skull fracture. All Menier's and all traumatic perceptive deafness, yielded complete recruitment in the administered battery of texts.

Foght (1944) found strong positive recruitment in all his menier's disease cases and observed over-recruitment occasionally. Newby (1965) stated that it may be difficult to rationalize the existence of hyper recruitment on any theoretical neurological basis.

Masking, Fatigue, Temporary threshold shift and Recruitment:

Fowler also pointed out that phenomenon of recruitment is helpful in diagnosing the perceptive deafness overcoming the flaws of inadequate masking leading a case to b diagnosed as conductive loss (1937).

Guttman and Ham (1928) encountered a manifestation of recruitment in some experiments of pure tone masking. They found that a tone of give intensity above threshold produces less masking in a particularly deafned than in a normal ear.

Langenbeck (1926) in his study on 8 patients with nerve deafness, 10 with conductive or mixed hearing loss and 4 normal subjects showed the intelligibility for speech in noise was different for the clinical groups, the group with nerve deafness suffering relatively more from increasing the intensity of a masking noise.

Langenbeck (1932) published him study on the problem of hearing in noise together with rather complete masking on 10 patients with conductive or mixed loss and 9 patients with nerve deafness, and with adequate information on the normal ear. He used saw tooth wave. He found that in some cases it was very difficult to distinguish types of hearing loss by the effect of masking of noise on pure tones, but in general, patients with nerve deafness exhibited greater masking than normal.

Huizing (1942) measured the masking of one tone by another as a function of the intensity of the masking tone. He found abnormally step masking functions to be associated with hearing losses the exhibited recruitment. He concluded that a sound's ability to mask is directly related to its loudness.

De Mare and Rosler (1950) studied masking effects in 12 normal's, 14 cases of conductive hearing loss and a few inner ear hearing loss cases. When the sensation level of the masking noise was equated, no difference appeared between normals and patients with conductive impairment. With inner ear hearing loss, on the other hand, the same SL had marked additional effect.

Bekesy (1930) used fowler's binaural loudness matching technique in the case of an ear partially deafned by stimulation with an 800 cps tone. He determine equal loudness contours through the range 300-2000 Hz at 4 intensity levels; the effect of fatigue though amounting to 30 dB at threshold, was reduced to very few decibels at the more intense levels; Harris (1952) stated that it could be explained by assuming the auditory fatigue produced an analogue of recruitment.

However, the information regarding the intensity, duration and post-experimental level of the fatigue is not available.

Larsen (1940,42)studied simulated or pseudo-recruitment by inducing residual fatigue in a normal ear with a loud tone, then conducting binaural balance test against the other, non-stimulated ear. The pitch of the 2048 cps tone use was shifted a half –octave higher than normal and the 30 dB residual fatigue at threshold was completely overcome by pseudo-recruitment at an intensity 80 dB over normal threshold.

De Mare (1948) first published a brief account of some experiments with short duration fatigue as it is related to perceptive deafness (and therefore presumably related to recruitment). He found a sharp difference between the amount of fatigue occurring in conductive hearing loss as against 'nerve deafness', but makes no point of possible correspondence between recruitment and fatigue.

Huizing (1949) gave a text procedure that he had found useful in testing for recruitment. His patients with recruitment when stimulated with the 2000 Hz tone for 3 minutes at 30 dB above the pathologic threshold gave threshold shifts of between 19 and 22 dB whereas at the same sensation level the threshold shift in normal's, conductive loss and nerve deafness cases without recruitment was within the range of 5 to 12 dB. Thus Huizing concluded that the amount of fatigue produced by a tone depends upon its loudness than to its intensity.

Hickling (1967) showed that in an ear with TTS recruitment would be linear and complete at a SPL of about 95 dB.

Hickling (1967) selected 7 listeners in the age range of 22-25 years. Temporary threshold shift was induced in them by 2.4-4.8 Kcls noise band in a reverberant room for 10 minutes of SPLs up to 108 dB according to individual susceptibility. Of the 11 ears performance considered by analysis, mean induced shift was 30 dB all demonstrated loudness recruitment. Measurement was made at 4 Kcls and complete recruitment was apparently present in all the ears.

Conductive Recruitment: The most marked difference between a conductive and a sensory-neural hearing loss is that, the latter, with extremely few exceptions, is supposed to show recruitment whereas the purely conductive hearing loss does not. The abnormally rapid growth of loudness in perceptively deafened ears is characteristic of inner ear lesions and absent in most cases of nerve fibre retrocochlear lesions. This division is so commonly accepted that the loudness recruitment occurs. When conductive impairment is accompanied by some degree of recruitment, it is usually attributed to an underlying sensory-neural component.

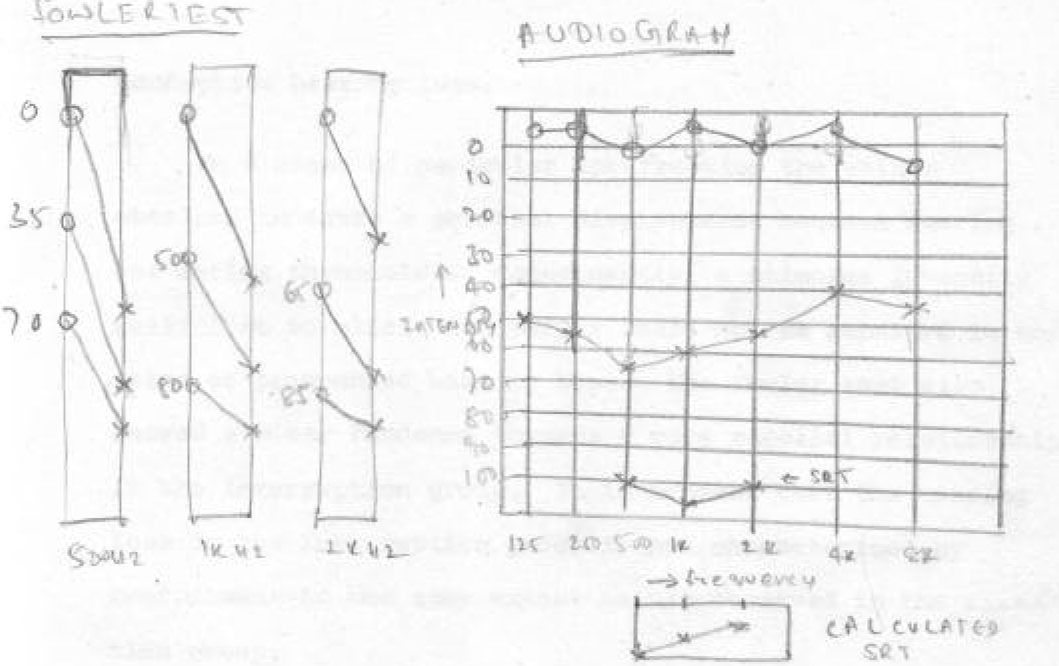
But the recent findings indicate the conductive loss is not entirely devoid of recruitment like properties and it was considered that a closer examination of this possibility might prove rewarding, particularly in view of the availability of new test methods.

Lider (1954) showed that the discomfort level for speech was only slightly higher for an otosclerosis group than for the sensory-neural groups with recruitment. Consistent with this is Hardford and Jergers (1959) observation in a study using delayed speech feedback.

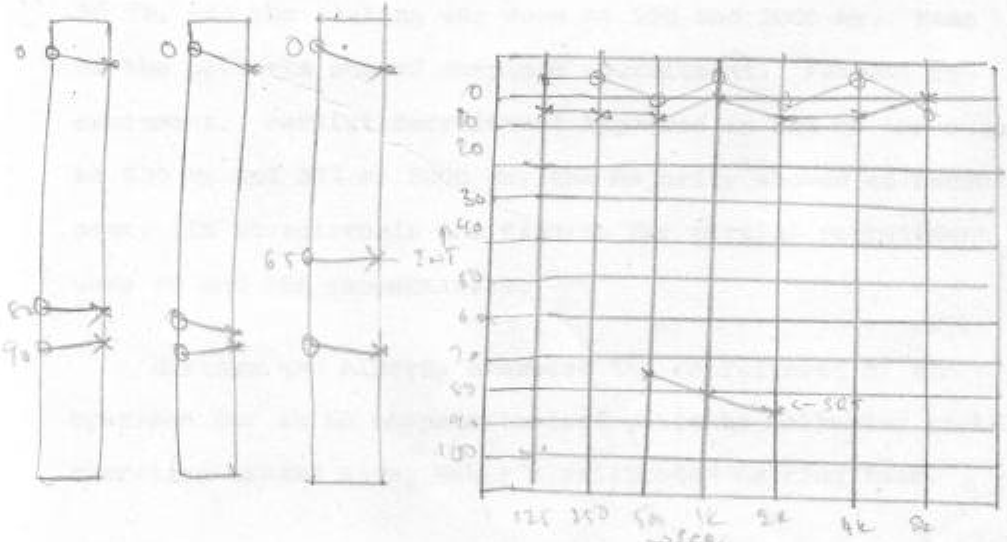
Single observations of recruitment in conduction deafness were recorded earlier by palva and ojala (1955) using Fowler's test, in 4 ears of 42 patients suffering from catarrhal or purulent otitis media. Recruitment was complete in 3 ears and incomplete in one. This recruitment of loudness was not due to inner ear lesions since bone conduction thresholds were either normal or returned to normal after aspiration of fluid.

The series of Anderson and Barr (1966) consisted of 30 ears, of which 24 were conductively deaf due to ossicle fixation (18 otosclerotic ears). In the remaining 6 ears, the loss was due to ossicular interruption. In addition to Fowler's test, the stapedius reflex text was recorded from the contralateral normal ear the stimulus being given to the impaired ear. In the 24 cases of ossicular fixation the difference between expected reflex threshold and the mean reflex threshold was 19 dB. This was still more marked in the group with severe hearing loss, where the corresponding difference was about 30 dB. Such a reduction in the distance between the hearing and reflex thresholds should when found in cases of sensory-neural impairment, be taken as indicative of a moderate degree of recruitment. To examine whether this phenomenon might be demonstrated also with a subjective recruitment text the Fowler test was performed in 18 of the 24 cases. The results showed the same tendency to non-parallel the relationship. Measurements were performed before and after hearing restoring surgery. For this case prior to the operation the fowler and reflex texts revealed distinct signs of recruitment. After the hearing has been completely restored, the fowler test showed normal loudness function, as did the reflex threshold, which had now been normalized. The phenomenon is manifested here as a lack of parallelism in the post-operative recovery for the hearing-and – reflex-threshold; for the hearing threshold the gain was about 60 dB, but for the reflex threshold only 25 dB.

Pre-operative and post-operative audiometric findings are shown in the figure. The results show that the most common type of conductive hearing loss- that caused by fixation of the ossicular chain, is characterized by a low grade but distinct recruitment that is detectable with conventional recruitment tests. It is clear, more over, that the degree of recruitment is dependent on the magnitude of the



Pre-operative And post operative (Lower) Audiometric findings in a case of Stapedial fixation



conductive hearing loss.

In 6 cases of ossicular interruption the values obtained indicate a parallel displacement between hearing and reflex thresholds. Consequently, stimulus intensity sufficient to elicit the reflex could not be attained in the cases of pronounced hearing loss. The Fowler test also showed a clear tendency towards a more parallel relationship in the interruption group. It is evident that the hearing loss in the interruption group is not characterized by recruitment to the same extent as was observed in the fixation group.

In the series of Ranko, 63 patients with unilateral conduction deafness were examined with the Fowler's ABLB test. 43 of them had chronic ear disease and 20 had otosclerosis. Hearing loss in the impaired ear did not exceed 50 dB, and the testing was done at 500 and 2000Hz. None of the patients showed complete recruitment. Partial recruitment appeared in 23% of the cases at 500Hz and 33% at 2000Hz; the majority showed no recruitment. In otosclerosis the figures for partial recruitment were 40 and 25% respectively.

Strauss and Alberty measured the recruitment of the operated ear in 50 stapedectomized patients following post operative trauma using Weber's calibrated hearing test.

Without masking, the BC threshold was obtained by placing the receiver on the patient's forehead, while the recruitment and the dynamic of the ear were measured by shifting the lateralization with each change of the sound level. An increasing reaction of the inner ear (Recruitment, decrease in the BC threshold) could be observed up to the 6^{th} post operative day. In some cases the extent of the inner ear reaction may illuminate the subsequent hearing process.

The midline simultaneous balance is different from ABLB text since a judgment of central localization is substituted for loudness balance judgment. Using tones exceeding 50 dB, inertia and compression bone conduction mechanisms begin to play an important part in the subjective sensation of localization, directly comparable to Weber's test. The method of midline localization is often considered to be less exact than the ABLB method for making loudness comparisons.

Palva and Karja (1975) administered a midline loudness balance test in 10 normal ears with blocked ear canals and in 104 conductively deaf ears with loss exceeding 45 dB. The test was made by giving the tones simultaneously in the ears at 10, 60 and 80 db sensation levels for 500 and 2000 Hz. In the normal group the midline balance method indicated no reduction from the threshold differences at any of the three levels whereas significant reductions occurred in all groups

of conduction deafness. The occurrence of true partial recruitment in conduction deafness demonstrated by ABLB (Fowler's) test was attributed to altered middle ear mechanics, loud tones stimulating the inner ear relatively more effectively than tones near the threshold level.
The midline balance method is more closely dependent upon bone conducted sounds and on the altered relative movements of the labyrinthine windows.

It is evident from these studies that pure conductive hearing impairment does not always function as a plug-in-the-ear sound attenuator, as it commonly suppose. This phenomenon of recruitment in conduction deafness is essentially similar to the regression typical of the sensory-neural loss. However, the recruitment in conductive loss never attains complete loudness balance in the Fowler text. More over, there is little if any recruitment, in the case of mild conductive loss, whereas for a sensory-neural impairment of the same magnitude the recruitment is usually complete.

The observation that a pure conductive impairment can display a moderate degree of recruitment should be taken into account into the clinical diagnosis. It is important that the conductive recruitment should not be mistaken for a manifestation of an underlying sensory-neural defect. Like wise, it provides an explanation of some earlier contradictory findings in conductive disorders.

Co-existence of Recruitment and Abnormal tone decay

Many investigators (Johnson 1965, Shapiro and Naunton 1967, Katinsky 1972) have reported the presence of recruitment (as measured by ABLB), high SISI scores and Bekesy type II tracings in surgically confirmed retrocochlear pathology cases. These investigators have tried to exaplain the presence of cochlear findings in confirmed retrocochlear pathology cases in terms of predominace of cochlear finding when both the lesions co-exist or as atypical findings.

Dix and Hallpike (1960) suggested that the tumor might interfere with cochlear blood supply thus creating a secondary cochlear lesion. To support this they have cited examples of two cases who showed absence of recruitment after the removal of the tumor.

Jerger and Waller (1962) suggest that the audiological signs change with progression of a lesion. In support of this they report a case whose speech discruimination became poorer and Bekesy tracing changed from I and II and II over a period of time.

Johnson (1965) suggests that site and size of the tumor influence the audiological findings.

These observations of cochlear finding in some confirmed retocochlear pathology cases is explained on the basis of the co-existence of the 2 lesions, progression of the lesion and site and size of the tumor.

M.N. Vyasamurthy (1976) reported a case of abnormal tone decay demonstrating recruitment. A case of 35 years old came with the complaint of hearing loss in the left ear. Audiogram showed left ear sensori-neural hearing loss (moderate) and right ear high frequency hearing loss. Speech discrimination was 25% in the left ear. ABLB test results showed complete recruitment at all frequencies (500 Hz, 1 KHz and 2 KHz). Carhart's tone decay test showed marked tone decay in left at all the frequencies (500Hz to 4 KHz) in left ear, and in right ear tone decay was negative. SISI text was 100% in left at frequencies from 500 Hz to 4 KHz. When modified SISI test was administered he detected 1 dB increments but the tone was fading. False SISI positive was observed. Impedance audiometry showed absence of reflex at 120 dB HL in left ear. This reported case exhibits both recruitment and abnormal tone decay.

It is not clearly known why the cochlear findings should predominate over retro-cochlear findings when both the lesions co-exist. One possible explanation for the presence of recruitment, high SISI score and Bekesy II tracing in confirmed retrochlear pathology cases in the influence of tone decay on these 3 test results. When recruitment is measured

Using ABLB (auto) test, tone decay seems to have no influence and hence recruitment may be expected even with abnormal tone decay (auto) is administered indicating that recruitment is typical in cases with abnormal tone decay (if recruitment is an artifact). The absence of recruitment in surgically confirmed retrocochlear pathology cases may be explained on the basis of the method of administration of ABLB test. High SISI scores in surgically confirmed retro-cochlear pathology cases may be considered as false SISI +ve. True SISI +ve may alos result in retrocochlear pathology cases on the basis of absence of tone decay. Low SISI scores or negative SISI test in surgically confirmed retrocochlear pathology cases is explained on the basis of marked tone decay (Yound and Herbet 1967). Or negative SISI scores in retrocochlear pathology cases may be considered as a failure of the test (M. N. Vysasamurthy 1976).

It can be inferred that the observation of cochlear findings (recruitment, II Bekesy tracings, +ve SISI test and negative TDT) in surgically confirmed retrocochlear pathology cases in due to the influence of tone decay, i.e., the absence of market tone decay or presence of mild or moderate decay or no tone decay. It this is true then the negative TDT is confirmed retrocochlear pathology cases should be explained.

1. Predominance of cochlear findings when both the lesions co-exist.
2. Matkin (1965) report that when both the lesions co-exist the retrocochlear findings predominate. If there is

abnormal tone decay it will be observed even when both the lesions co-exist. So the test may be considered insensitive in identifying retrocochlear pathology cases.

The demonstration of recruitment in a patient with a sensori-neural hearing loss does not warrant the exclusion of the diagnosis of acoustic neuroma. In Menier's disease, on the other hand, recruitment is almost invariably present. Spikes and Dips in the audiogram of 15 dB or more at certain frequencies or a rise at 8000 cps may suggest an early acoustic neurinoma, Poor speech discrimination also points to a nerve trunk rather than intra-cochlear lesion.

Central Processes and Recruitment

Certain facts lead to the belief that recruitment may be secondary to central processes perhaps to disturbances of a regulation center of the cochlea. The arguments in favour of this idea are:

1) Audiometric: Study of the biauricular integration test and study of the cenral control of auditory fatigue.
2) Clinical: The regulating centers of the cochlea are located on a level with cerebral trunk whose dysfunctioning involves cochlear-vestibular disturbances. Along with the role of transmission of sensory messages, it is also necessary to emphasize the importance of the reticulodiencephalic

Effects explained in the works of Magon. The diencephalon is mainly responsible for vegetative regulations and it is not paradoxical to think that the normal funcitioning of the cochlea necessitates constant regulation of the diencepthalon to regulate the composition and intensity of endolymphatic liquids.

Dr. Kirsten Osen described the nervous pathways inducing ‘central recruitment’. The octopus cells in the dorsal part of the dorsoventral cochlear nucleus are so situated that incoming impulses must pass through their area. Their afferents pass to the retro-olivary bundle, where the afferent bundle of Rasmussen originates, and carrying inhibitive impulses. This short reflex consisting of three neurons has constant tonus, inhibiting unwanted impulses. Now, if this tonus should be disturbed, due to a disease or due to a tumor somewhere along its course, the inhibition would fail, the impulses pass indisturbed, and you would have a “central recruitment”.

A brain stem lesion above the level of the cochlear nuclei can only give rise deafness if it involoves the conchlear pathways bilaterally and in this event there shoul be deafness at both ears. Rose et al (1960, 1963) found that there is present in the brain stem a tonotopic organization of the auditory fibres at all levels.

In the Kernicteness cases as well as in most of the retrocochlear disorders, very obnormal distorted patterns have been observed which indicate that the lesion must be also partly peripheral, and the hearing loss is symmetrical even in these cases (J.M.Aran).

There is a great loss of nerve cells in the cochlear nuclei following Kernictenes. The bilurubin hampers the oxygen carrying ability of the haemoglobin, so the cells disintegrate, either from the toxic effect of the bilurubin or of asphyxia (j.G. Hall 1964).

More recent studies including those of Liden (1969) and Carhart (1967) incline to the view that loudness recruitment is a feature of brain stem disorder. Blakeley (1959), Floltorp et al (1957) and Matkin (1965) have all reported similar findings. In addition there is now a substantial body of histopathological evidence based on the examination of temporal bones (Wolf 1956, Crabtree & Gerrad 1950, Goodhill 1956) that end organ involvement is conspicuously absent in Kernictense.

M. R. Dix and J. D. Hood (1973) carried out an examination of bilateral deafness resulting from prouch lesion of the brain stem and found a symmetrical hearing loss in all this cases. In these the lesion is know to involve the cochlear nuclei and on this account it must be presumed that the symmetry of the hearing loss reflects a similar symmetry of the lesion. A second possibility that can be considered is that the deafness resulted from either a symmetrical bilateral nerve fibre or cochlear lesion. In all cases of confirmed brain stem lesion loudness recruitment was a constant finding and hence the former possibility was ruled out. As to the latter possibility is considered, deafness is shown to be a related symptom of the disorder in all cases. The occurrence of a coincidental cochlear lesion would imply a statistical improbability. It is of some significance that in all the cases they have examined the caloric responses were normal. This would suggest that the lesion is at a level where the cochlear and vestibular fibres have separated. It is therefore inferred that the presence of recruitment in these cases results from derangements of the cochlear nuclei.

The occurrence of loudness recruitment in brain stem lesions has obvious and important theoretical implications. It seems to imply either that the mechanism of recruitment in brain stem lesions differs from that commonly attributed to end organ lesion or else more research is needed for some revision of this. In this event the recognition of symmetrical hearing exhibiting loudness recruitment in patients with known or suspected brain stem lesions could well be a localizing of some significance.

CHAPTER IV

TESTS FOR RECRUITMENT

4.1 <u>Introduction</u>

A test of pure cochlear function is of obvious value in assisting the otologist in the diagnosis of the anatomical locus of the lesion in perceptive type hearing losses. Given the air conduction and done conduction thresholds, and can effectively differentiate conductive from perceptive losses in most instance, the question quite often arises as the whether the lesion causing the loss in perceptive type cases is confined solely to the end organ or whether it is situated at some point along the auditory nerve pathways. The ability to rule out either a cochlear or non-cochlear lesion in perceptive type losses is of singular importance in cases which lack significant medical history and objective symptoms, such losses could for instance be cause by an acoustic tumor. The immediate ability to rule out cochlear involvement in this case, provides a much speedier diagnosis. From this standpoint, an audiometric procedure which examines only the function of the inner ear would be of certain clinical value.

Hearing losses in cases of rubella, high fever diseases in general, congenital deafness, senility, ototoxicity, fenestration operation in otosclerosis results in perceptive deafness, but it has not been consistently possible to determine differently where the primary lesions in these disorders are located.

Tests for the detection of loudness recruitment may be readily applied, at first, to the problems enumerated above; there is no question that the presence of this phenomenon indicates an end organ involvement. A clinical technique known to test the function of a particular part of the end organ would seem to be of great practical, as well as theoretical significance. However traditional recruitment tests are not always satisfactory in testing all patients and in indicating the anatomical region of morbidity.

Alternate binaural loudness balance and monaural bi-frequency loudness balance tests are used but because a difference of 25 dB between ears or between frequencies in a ear is must, some patients can't be tested.

Serious questions have been raised as to the actual validity of Difference Limen tests in discriminating the recruitment phenomenon. Little information is available concerning the anatomical or physiological process involved which account for the phenomenon.

The use of electrical potentials as a measure of inner ear function has been based on the fact that stimulation of the sensory cells of the organ of corti by sound is intimately related to the production of ac potentials which may be detected and amplified by sensitive electronic equipment.

The primary value of aural overload test is that it is known to be a measure of sensory cell function. The evidence comes from animal experiments employing the electrical potentials recorded from the region of the cochlea and which are directly related to the activity of the sensory cells of organ of cortic.

Other experiments which have produced a deterioration of the inner ear have also revealed contraction of the dynamic range over which the sensory cells operate as revealed by the electrical potentials. The first indication of the shortened dynamic range is the lowering of the point of departure from linearity with respect to some pre-established sensitivity level.

There is no doubt the electro-acoustic impedance measurement are rapidly reaching a point of great importance in diagnostic audiology. The sensation level at which the stapedial muscle contracts on sound stimulation is lowered in cases of recruitment.

For many years Bekesy Ausiometry has been recognized as a procedure that allows the patient to track his own threshold, and goes beyond the more automatic recording of pure tone thresholds. Extreme narrowing of the swing widths was thought at one time to be related to the DL for intensity of so indirectly to recruitment.

Brief tone Audiometry examines the relative threshold differences among pulse tone which vary in their duration comparison of the relative threshold differences among the short tones used in BTA may be utilized to establish a differential among various types of auditory disorders.

None of the tests in this chapter is infallible. Instead of diagnosing based on the results of one test it is better, if the information obtained from different tests are considered before diagnosing a case as exhibiting loudness recruitment. All of the results must be compared to the pure tone and speech audiometric results and above all to the patient's history.

4.2 Loudness Balance Procedures

Tests for loudness recruitment can be divided into the direct and the indirect. Direct tests of loudness recruitment can be performed on a great majority of patients and obviously are the procedure of choice in its direction and measurement.

In these supra-threshold tests, the increase in loudness at a certain frequency in the affected ear is directly compared with that in the normal ear at the same frequency (Fowler 1928, 1936) or at 2 different frequencies (Reger 1936), one tested with normal and the other with impaired hearing.

Basically there are methods in performing loudness balance procedures:

Method of Limits: Perhaps the most widely used psychophysical method. This procedure requires that the examiner manipulate the intensity of the signal while the patient judges its relation to a criterion (Stevens 1951).

Method of adjustment: In this method. The patient adults the stimulus until it is subjectively equal to criterion (Stevens 1951). This method requires the modification of commercially available audiometers, but many believe the results obtained are far superior to the method of limits as it is usually applied clinically (Jerger 1962).

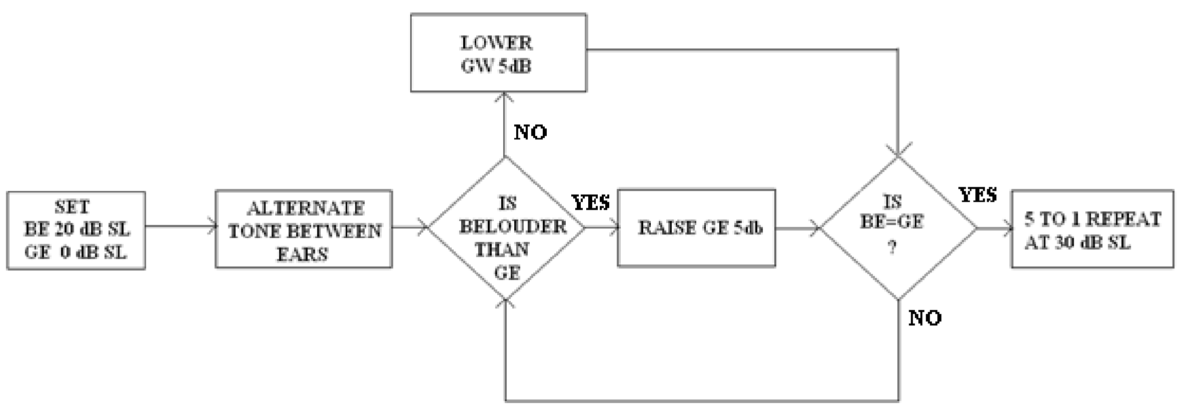
Alternate Binaural Loudness Balance Test

The procedure preferred by most audiologists as a test for recruitment in the ABLB. There are several versions of this test and different procedures are favored by different clinicians.

The candidate for the ABLB procedure must have normal hearing in one ear for the frequencies to be tested. The hearing in the poor ear should be at least 25 dB poorer than the hearing in the better ear.

The purpose of ABLB test is to compare the growth of loudness in an impaired ear with the normal growth of loudness in the opposite ear. In this way, the degree of recruitment, if present, can be demonstrated.

Administration of ABLB test



FLOW CHART FOR PERFORMANCE OF ABLB TEST

Tracking method of ABLB in recruitment testing:

Miskolczy-Fodor (1964) introduced a novel ABLB procedure, in which the tone at the reference ear (target tone) increases or decreases in level at a fixed rate in dB/sec. A comparison tone level also changes at a fixed rate; however, the speed is faster than for the target tone, and the direction of level change is controlled by the subject using a modified Bekesy audiometer. Subject thus tracks an equal loudness relationship between the variable target and comparison tones.

The advantages of the tracking method are the speed with which a complete loudness function can be generated; a task which is simple to demonstrate and carry out and a simultaneously recorded permanent record.

Carver (1970) compared the ability of the tracking method and the standard ABLB to yield the expected 1:1 loudness relationship between the ears of 12 normal hearing subjects as well as the reliability of the 2 methods. He found that tracking method was less precise than the fixed level method.

Gelfand, A (1976) used a modification of the above procedure in level change speeds and provided only an ascending target tone and compared the tracking method with the standard ABLB in 15 normal and 30 subjects with asymmetric and unilateral sensori-neural losses. Compared to the standard ABLB, the tracking method overstated recruitment when the variable tone was directed to the poorer ear, and understated it when the variable tone was directed to the better ear. Over and under-shoot artifacts make the tracking procedure undesirable for experimental or research applications.

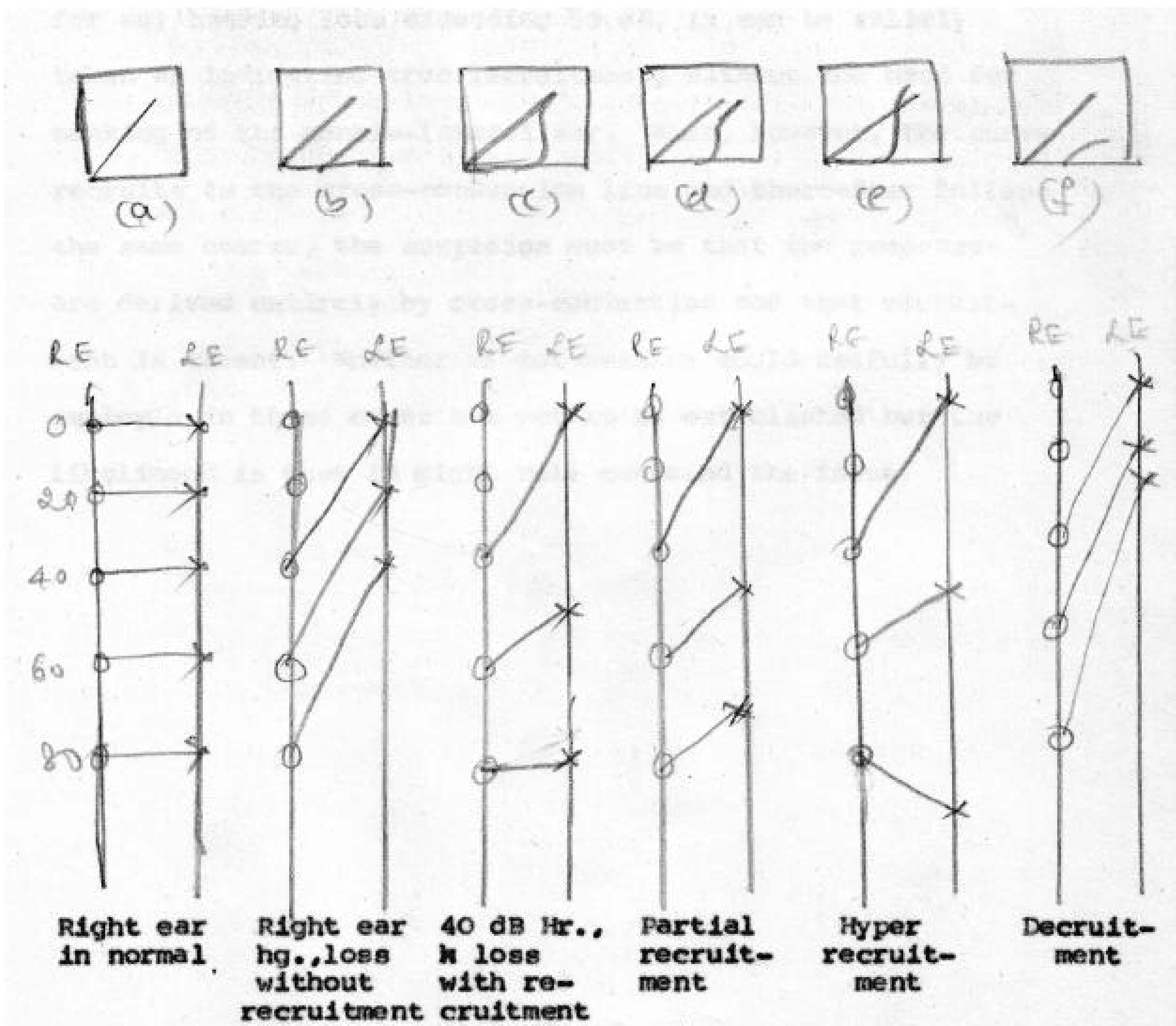
Recording and interpretation of results

The data obtained should then be recorded in a manner which will illustrate the growth of loudness in the impaired ear as it compares with the reference ear. One of the 2 kinds of illustration can be used.

One is called a laddergram, it looks like an abbreviated audiogram. The rung (of the ladder) at the top is equivalent to 0 dB hearing threshold level. The successive rungs represent higher and higher hearing levels. Thresholds are plotted and then the average variable ear loudness levels for the several trials at each reference level are plotted as on an audiogram. The variable plot is connected by a straight line to its corresponding reference level plot.

The other method used to illustrate loudness growth is a graph, where the poorer ear data are plotted from the abscrissa and the better ear for the ordinate. Again the numbers represent hearing threshold level. The 45° line represents equal loudness growth for two normal ears. The points which are plotted are usually connected by a curve of best fit.

Laddergrams and the loudness balance graph illustrating the different possible results are shown in the figure at different audiometric frequencies.



Masking and ABLB

Suggestions have been put forward in the past that when hearing loss at the impaired ear exceeds 50 dB or so, masking should be applied to the better ear in the course of the ABLB test in order to eliminate the loudness contribution from that ear which would result from cross conduction. In consequence, the safe rules to follow is that when recruitment is evident above the cross-conduction line for any hearing loss exceeding 50 dB, it can be validly taken as indication true recruitment, without the need for masking of the contra-lateral ear. When, however, the curve recruits to the cross-conduction line and thereafter follows the same course, the suspicion must be that the responses are derived entirely by cross-conduction and that recruitment is absent. Whether or not masking could usefully be employed in these cases has yet to be established but the likelihood is that it might well confound the issue.

Monaural bi-frequency loudness balance test

Recognizing the advangtages of determining the presence or absence of recruitment and recognizing that it is not always possible to administer the ABLB test, Reger (1936) developed a different procedure for testing recruitment. This procedure measures the growth of loudness of two frequencies in the same ear and is called the monaural loudness balance test.

This MLB test is designed to compare the growth of loudness of one frequency (which demonstrates a hearing loss) to the growth of loudness of another (normal) frequency in the same ear. The difference in thresholds between the two frequencies should be at least 25 dB.

Administration of the test

Two channel audiometers allow for the performance of this test. The input must be the 2 frequencies, with the output fed to a single earphone.

In administering the test, the intensity is set to 10 to 20 dB above the threshold of the frequency at which hearing sensitivity is poorer. The tone are then pulsed from higher to lower frequency, and the patient is asked to aid in the manipulation of the hearing level dial controlling the intensity of the normal frequency, when he determines that the ‘high tone’ and ‘low tone’ are equal in loudness, that portion of the test is complete. Intensity is raised in 10 dB steps for the poorer hearing frequency after each judgment until recruitment is seen or the maximum limit of the audiometer is reached.

The method of recording and interpretation of results are similar to that of the ABLB test.

In the comparison of loudness levels at different frequencies with automatic testing the technique is somewhat more demanding than with other comparison methods and a few subjects had real difficulties in the test.

Reger’s test can well be carried out, using automatic test techniques, for frequencies differing by more than 2 octaves all test subjects in the series managed the comparison of all frequency pairs without much difficulty.

Seppo Karjalainen compared the loudness levels of different frequencies of pure tones, both monaurally and binaurally. He represented the equal loudness contours in the form of scale graphs. A reduction of the initial loudness level differences normally took place in frequency pairs in which one of the two test frequencies was 125 or 250 Hz. Of the high frequency pairs, balancing occurred with a sensation level difference exceeding 5 dB only at 1000-4000 Hz and 1000-8000 Hz. By comparing the Reger test results with the presented scale graphs the possible recruitment in cases of hearing impairment can be quickly established and is not confused with the physiological loudness recruitment between frequencies.

4.3 Loudness discomfort level test

It is of particular relevance since it constituted a very simple method of assessing the presence of loudness recruitment in cases of bilateral deafness. In cases of bilateral deafness ABLB and MBFLB tests have only a very limited value. In case of difference Limen tests, a subject with unilateral Menier's disease is likely to show a reduced DL in the affected ear compared to the normal ear, but the 2 values taken separately might well fall within the range of values in a group of normal hearing subjects.

It is the loudness discomfort level which has now been put to practical use by Hood who, in co-operation with poole has made use of it in developing a new and simple test for loudness recruitment. The procedure used to attain the loudness discomfort level is a simple one. The subject is presented with short bursts of tones at different intensities and the level marked at which he first experiences a sensation of discomfort.

The percentage distribution of the loudness discomfort level is 200 normal hearing subjects done at frequencies 500, 1000, 2000 and 4000 Hz show considerable agreement as to what constitutes an uncomfortable loudness level. Approximately 90% of all subjects selected levels between 90 and 105 dB with an average value of 98,98.2,98.9 and 95 dB respectively.

In 100 patients with unilateral Menier's disease, in all of whom the presence of complete loudness recruitment of the affected ear had been confirmed by means of the alternate loudness balancing procedures, loudness discomfort levels were established at one or more of the four frequencies 500, 1000, 2000 and 4000 Hz. Despire the fact that the hearing losses of the Menier's group extended as high as 80 dB, the distribution of th loudness discomfort levels remains remarkably similar to that of the normal group. It is clear, therefore, that in this group with proven loudness recruitment the hearing span between the threshold of hearing and the loudness discomfort level is considerably reduced. The most remarkable aspect of the results is the constancy of the loudness discomfort levels for all degrees of deafness; thus there is no discernible upward trend of the loudness discomfort levels with increasing hearing loss.

Investigations have been extended to include a further group of subjects with unilateral deafness due to a variety of vascular lesion affecting the cochlear end organ in all of whom the presence of loudness recruitment had been established by means of the ABLB procedure. The results are in all respects similar to the Menier's group; in fact the average loudness discomfort level is only slightly higher at 101 dB.

The point seems to be well established therefore, that in subjects with end-organ deafness, in whom loudness recruitment has been shown to be present by means of the alternate balancing technique or in whom the nature of the lesion leads to the expectation of loudness recruitment, the loudness discomfort levels can be shown to be consistently within the intensity range 95 to 105 dB irrespective of the magnitude of hearing loss.

In case of nerve fiber deafness the loudness discomfort levels are in general considerably higher than in the conductive group. With unilateral conductive deafness the loudness balance curve remains parallel to the normal but displaced from it by the amount of the deafness, while in unilateral nerve fiber deafness the phenomenon of recruitment reversal is not an uncommon one. The diagnostic value of loudness recruitment depends not only upon the demonstration of its presence in end-organ deafness but also of its absence in conductive deafness and in particular, nerve fiber deafness.

No equipment other than a standard audiometer is required for the loudness discomfort level test. The test is thus available to any practicing Otologist and can be carried out in routing practice when testing for a subject's threshold of hearing.

4.4 <u>Difference Limen and Recruitment</u>

The difference Limen for intensity is the smallest change in the intensity of a pure tone which can just be detected. It is usual for persons with normal hearing to have difficulty in detecting small changes in intensity closed to threshold. As intensity increased DLI decrease. There appears to be a strong relationship between the ability to detect small intensity changes at relatively low sensation levels and the presence of loudness recruitment. Many clinicians have assumed that a small DLI is an indirect indication of recruitment, and others have assumed that the DLI and direct tests for recruitment measure related pathologic phenomena.

Difference Limen as a possible indicator of recruitment was based on the assumption that a recruiting ear, compared to non-recruiting ear compressed more loudness units into a give range of intensity, it was believed that an intensity increment would accordingly nvolve more loudness units and thus be more noticeable. By extension, the intensity increment needed for adjust noticeable difference in loudness would be smaller for a recruiting ear than for non-recruiting ear.

When it was reported in 1948 by Dix et al that loudness recruitment was typically present in cochlear sensory neural hearing loss it was suggested that result of measurement of the loudness recruitment phenomenon could be used as a diagnostic in the differentiation fo cochlear and retro-cochlear loss. As a search for a simple, easily administered clinical test for recruitment commenced and 'Intensity Difference Limen' received attention as a possible indirect measurement of recruitment.

Although DL measurements seemed to be a straight forward and uncomplicated process, the experimental result among several investigator have differed greatly, as a result, until recently no comprehensive statement describing this loudness domain has emerged. Through the years it has been accepted that these difference in Dl size arose because of varying experimental procedures, stimulus conditions, individual subjects, psychometric methods and apparatus.

Harris (1963) described and classified various methods use for measuring dl for intensity; the three procedures are loudness-masking, loudness-modulation and loudness-memory. This re-evaluation helped to explain the supposed inconsistencies of previous investigators.

Dallos and Carhart reported a study evolving from the fact that there was one point of agreement among the results of prior researchers; the size of the just noticeable difference (jnd) for loudness modulation diminishes with increased sensation level.

During the late 1940's and early 1950's the test of difference limes became popular as a means for determining the presence or absence of recruitment.

Luscher and Zwislocki described a DL test that was administered at a sensation level of 40 dB. It involved the presentation of a tone that 'wobbulates' in intensity, i.e., varies in intensity so that the patient hears intensity beats. The examiner than reduces the wobbulation gradually until the patient reports the tone sounds 'steady'. The amount of intensity variation occurring at the point at which the patient signals the tone is no longer fluctuating in his Difference LImen. An abnormal DL is one that is smaller than the minimum value within the range of the norms established by Luscher and Zwislocki.

Denes and Naunton developed a test that compares the size of the patient's DL's at sensation levels of 4 and 44 dB. In determining the size of the DL at each sensation level they use 2 separate tones at the same frequency, one tone held constant in intensity and the other varied. These

Tones are presented to the patient's ear alternately. In the beginning the tones are of equal intensity, but as the test progresses one tone is varied until the patient reports he can detect a difference in intensity between the tones. The amount by which the intensity of the variable tone differs from the tone of constant intensity at this point is the patient's Difference Limen. Denes and Naunton were not interested in the obsolete size of the patient's DLs, but only in the differences in the value of the Difference Limens at the 2 sensation levels. They determined that normal ears had fairly wide differences, with the DL at 4 dB SL being greater than the Dl at 44 dB. They gave a range of norms for DLD. In the impaired ear (recruiting) the difference in DL was reduced.

Jerger experimented with 2 different tests on the DL for intensity. He first employed a technique similar to Luscher and Zwislocki, except that he presented the tone at a sensation level of 15 dB, and he started with a steady tone, gradually introducing intensity changes until the patient reported the tone was fluctuating in intensity. Later he gave a DLD test similar to Denes and Naunton, he compared the size of the patient's DL at sensation level of 10 dB and 40 dB and used a single wobbulating tone for determining the size of the Difference Limens.

(i) Short Increment Sensitivity Index

In 1959, Jerger, shed and Harford described a test technique designed to differentiate subjects who were able to detect very small amplitude changes, presented periodically, in a pure tone signal. Having observed that many ears with a sensitivity loss due to abnormal cochlear function appear to have extremely keen discrimination for small changes in tonal intensity, these authors defined a relatively simple task, both for the examiner and for the subject, which they called the short increment sensitivity index or SISI.

The SISI test consists of superimposing brief bursts of 1 dB intensity increments on a sustained tone presented at 20 dB SL at each frequency to be tested. The test is administered monaurally through earphones. The patient instructed to report any 'jumps in loudness' he detects while listening to the sustained tone for a period of about 2 minutes. Each increment has a rise time of 50 m.sec, duration of 200 m.sec, and a decay of 50 m.sec. The size of the increment can be 0 dB, 1 dB upto 5 dB steps, but the test is scored only on the percentage of 1 dB increment correctly indentified by the patient. During the test 20, 1 dB increments are presented. All the 28 increments are presented in a series. First five increments presented are 5 dB in size in order to provide the patient a noticeably intense increment to which to respond. Nest 5 increments are 1 dB in size. If the patient responds to 3 or more of these, the size of the 6^{th} increment is set to 0 dB as a control presentation. If the patient responds to 2 or less of the first five 1 dB increments, size of the 6^{th} increment is set to 5 dB to enable him once again to respond positively. The responses to the 20, 1 dB increments are scored.

Results of SISI can be reported as percentages scored at each frequency or they can be graphed on a SISI gram which has frequency on the abscissa and percentages ascending from 0 to 100% in the ordinate.

Jerger (1962) presented a general discussion of the SISI test as one of a battery of useful techniques in otologic diagnosis. He mentioned that his experience indicated scores between 0 and 20% for those with normal hearing with conductive loss and with VIII nerve involvement and scored between 60% and 100% (at frequencies above 1 KC) for patients with cochlear pathology.

Jerger (1961) compared the consistency of the SISI test, Bekesy automatic audiometry for continuous and pulse tone stimuli (1960) and ABLB recruitment test in differentiating patients with conductive, cochlear and retro cochlear lesions. The SISI criteria he used were that (a) scores greater than

55% depict a ‘Positive’ response, indicating abnormally keen sensitivity to small intensity increments; (b) scores falling between 20 % to 50% were in the ‘Questionable’ category and (c) those less than 20% were negative. The results show that those with cochlear involvement appear to be the most sensitive to the 1 dB increments of the test.

Martin and Salas tested 12 subjects with unilateral hearing loss (cochlear) at 4 KCLs. The SISI test was administered in each ear at the standard 20 dB SL and again at a level equal in loudness to 20 dB SL on the opposite ear. The test was also administered to the good ear at the same SPL as yielded 20 dB SL of the bad ear. A positive relation was seen between the score on the SISI test and the SPL at which the carrier tone was presented.

Elmer Owens administered the SISI test to 27 subjects with normal hearing, 95 patients with cochlear lesions, 15 patients with VIII nerve lesion and 3 patients of uncertain classification because of discrepancies between audiologic and neurologic findings. Test scores for patients with cochlear lesions were typically 0%. From these results, the SISI test seems highly useful in providing audiologic information regarding site of lesion.

Cooper and Owens (1976) advised 2 major changes in the parameters of SISI test's routing use, to extend its clinical applications.

1. A presentation level of no less than 90 dB hearing level; and
2. A bimodal interpretation of results based on the premise that loss scores indicate extensive cochlear damage or neural dysfunction and high scores normal cochlear function.

Young and Herbert (1967) obtained the SISI scores at various SPL for 111 subjects. SISI scores obtained in normal and in pathologic samples without abnormal adaptation indicate that the intensity level reaching the inner ear is the determining factor in perception of the 1 dB increment.

If the inner ear receives an audible signal of 60 dB SPL or higher, there is essentially no difference in the performance of the SISI test of ears with normal hearing, conductive pathology or non-adapting sensori-neural hearing loss. While it is true that conductively deafened ears generally obtain loss SISI scores when the test is given at the conventional 20 dB SL, this is attributed to the effect of the conductive barrier in reducing the signal reaching the inner ear to a level below 60 dB SPL. If the residual signal is greater than 60 dB SPL after the conductive barrier is subtracted, the conductively-impaired ear behaves like a normal ear. Low scores obtained in sensori-neural hearing loss without abnormal adaptation and attributed to hearing losses being sufficient small so that the 20 dB SL carrier signal is less than 60 dB SPL. The most striking finding is the abnormally adapting ears obtain low SISI scores regardless of the SPL of the carrier signal. Based on these findings SISI test may be used more meaningfully as another measure of abnormal adaptation.

It is suggested that the SISI test be administered at 70 dB SPL or higher if required for audibility. IN conductive or mixed deafness, the conductive barrier in dB should be added to the 70 dB SPL test signal to obtain a positive score. They conclude that:

1. A positive SISI scores in an ear with pure sensori-neural hearing loss merely means that the test ear is responding as a normal ear at equivalent SPL and is probably of no diagnostic significance.
2. When the negative SISI scores occur in conductively deafened ears it is due to the conductive barrier which prevents the cochlea from receiving signals at intensities where the SISI is normally positive.

3. A negative SISI scores in the absence of a conductive barrier occurs only in abnormally adapting ears and is another measure of abnormal adaptation.
4. Negative SISI findings are significant if it can be shown that the test is valid.
5. Instead of using small increments to demonstrate increased sensitivity due to presumed cochlear pathology, it might be better to use large increments to show decreased intensity difference limens in abnormally adapting ears even at high intensity.

SISI test and masking: Since the SISI is a supra-threshold procedure, the problem of cross-hearing presents itself often. When the hearing threshold level of the SISI carrier tone is above the bone conductive threshold of the opposite ear by an amount greater than the patient's inter-aural attenuation, the non test ear is involved in the test. Cross-hearing for the SISI is stated as:

$$\text{SISI HTL (test ear)} - \text{IA} > \text{BC (non test ear)}$$

Masking for SISI is similar to that of speech audiometry. If the audiometer is calibrated in units of effective masking, the effective masking level of the masked ear is equal to HTL of the SISI carrier tone minus IA (40 dB) pulse any air-bone gap in the masked ear at the test frequency.

EM=SISI HTL (TE)-IA+A-B GAP (NTE)

(ii) <u>Frequency Increment Sensitivity Test</u>

The clinical use of Difference Limen for intensity (DLI) and Difference Limen for Frequency (DLF) had a fairly parallel beginning in the late 1940's and 1950's.

The study of Ross et al (1965) used a 2 tone type DL measure in which both the DLF and DLI were obtained. Several other auditory measures were also made in an attempt to establish a measure that would be useful in predicting the speech discrimination score in quiet or in noise. The results of the study revealed a highly significant difference between the mean DLF results showed mean score difference which were significant only at 2000Hz, while the other test frequencies were not significant.

The studies concerning the DLF indicate that a difference in DLF does exist between listeners with normal hearing and those with cochlear hearing loss. It also appears that a value of 1.0% DLF may serve to divide the results of the two types of listeners. Thus, a new DLF procedure, utilizing a method that has been thoroughly examined in the SISI, should employ the 1.0% value as an increment size to discriminate normal hearing from cochlear hearing loss.

Cambell J.D. tested 11 normal hearing subjects and 11 subjects with cochlear hearing loss with FIST (Frequency Increment Sensitivity Test).

The basic FIST was administered to the better ear of all subjects at a sensation level of 20 dB. The base frequencies of 500, 1000, 2000 and 4000 Hz were used. A continuous tone was presented in which the frequency changed incrementally every 5 sec. This frequency change was 200 msec. , long in a smooth sinusoidal variation. The variation started from the base frequency, increased to the maximum value, and returned to the base frequency. The difference between the maximum (or peak) frequency during the increment and base frequency was the measure of increment size. This size was represented as a percentage of base frequency. (A 1% frequency increment of 2000Hz would represent 20 Hz of change or a maximum frequency of 2020 Hz). Practice for the FIST was given at 5.0, 3.0 and 2.0% increments. Twenty of the 1.0% increments made up the scored portion of the test. Foil increments of either 0% or 3.0% were given about every fifth test increment. The proportion of the 20 test increments identified correctly by the subject was recorded as a percentage score, 5% credit for each correct response.

All subject were tested

with several variation of the FIST in addition to the basic test. The first few FIST runs for each frequency were given at test increment sizes of 0.8, 1.0, 1.5 and 2.0% of the base frequency, at 20 dB sensation level. The next few tests were given with the 1.0% increment, but at 10, 20 and 40 dB sensation levels. The final combinations were 2.0% increment at 40 dB sensation level.

This study has shown the FIST is practical, that it can differentiate between normal and damaged cochleae, that certain increment size seem best and that the 20 dB sensation level is unable. One may say that any score greater that 80% correct most likely comes from a normal cochlear, but it would take a score of 100% or high scores at several frequencies, to make a more definitive statement.

4.5 Brief Tone Audiometry

Brief Tone Audiometry, the measurement of pure tone thresholds with tones of extremely short duration, is a promising procedure in diagnostic audiology. It is based on an interesting phenomenon of audition- the ability of the ear to accumulate and integrate acoustic energy over a period of time. If a listener's threshold is determined for a very short tone and then the stimulus length is gradually increased, the listener will experience an increasing loudness, even though the intensity of the tone is held constant.

As the stimulus duration, is increased, the ear is able to use the additional energy in the longer tone, thus in a given ear a threshold response will be obtained for a relatively long tone at a lower intensity than the required for response to a very short tone. The integration of energy over time appears to continue as the stimulus duration is increased up to a critical point. Increasing the duration beyond this point bring about no further improvement in threshold, indicating that at this critical duration the ear is getting sufficient energy for maximum sensitivity. Although the temporal integration of energy occurs as a normal phenomenon in the unimpaired ear, this normal function appears to be significantly affected by the presence of cochlear pathology.

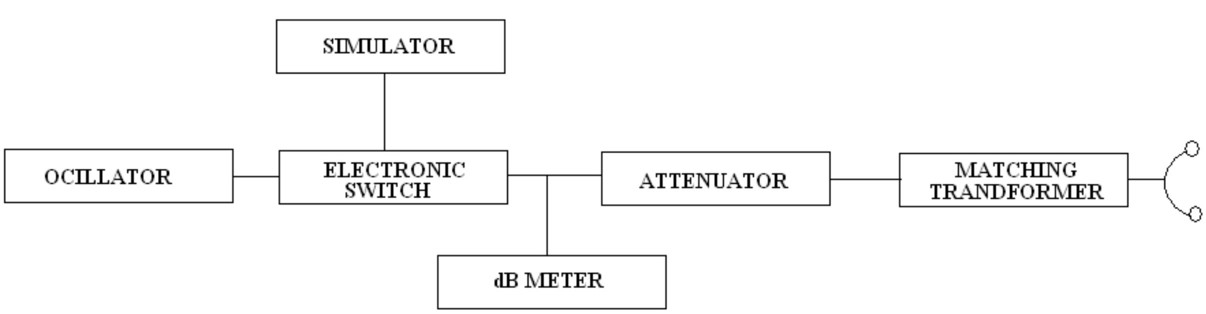
Previous investigators have shown that the integration function in the normal ear is linear with scope of approximately 10 dB per log unit change in duration. Thus if we determine threshold and critical duration for a pure toe in a normal ear and then decrease the length of the tone to one tenths the critical duration (1 log unit decrease), we will have to increase intensity by about 10 db in order to obtain a threshold response to the shorter tone.

Brief Tone Audiometry in patients with cochlear pathology: In patients with cochlear pathology, an increase of 3 dB is enough to get a threshold for a tone which has a duration of 1/10th of critical duration. This is what is known as decreased or abnormal temporal integration function.

Miskilczy-Fodor attributed this less steep function in the ear with cochlear pathology to the phenomenon of abnormal growth of loundness at suprathreshold levels (loudness recruitment). He therefore considered that by measuring the Temporal Integreation function in cochlear impaired ears we actually test the presence or absence of loudness recruitment.

Harris et al agreed with Fodor's assumption that abnormal temporal integration and cochlear pathology occurred together. These investigators however suggested that differential findings might make integration testing a significant diagnostic procedure.

Sanders and Honing (1967) determined the temporal integration function for all subjects with the brief tone audiometry procedure. The schematic diagram of the apparatus used is as shown in the figure.



The test frequencies includes were 250, 1000 and 4000 CPS. With the normal hearing subjects the frequency and the ear were varied systematically to provide control for the possible variables of fatigue and learning. All threshold determinations were made in 1 dB steps with the Hughson-Westlake ascending procedure. For each subjects at each frequency the procedure was

1. Threshold determination for a 200 msec. tone
2. Determination of critical duration to (found by varying the stimulus duration while keeping the intensity constant at threshold level)
3. Determination of threshold at a duration of 1/10 to (this duration is the reduction of one log unit for critical duration)
4. Threshold determination for stimulus duration at evenly spaced points in time between to and 1/10 to.

Four different thresholds were obtained at 200 msec. , at a stimulus duration of one log units less than the critical duration and the 3rd and 4th at points intermediate in time to the critical duration to and the duration one log unit les than to make possible a graphing of energy integration function. The results of this study led to the following conclusions:

1. Ear with cochlear pathology is clearly distinguished from the normal ear by Brief Tone Audiometry.
2. Brief Tone Audiometry appears to be an unusually sensitive diagnostic tool.
3. It might be a successful or useful technique in differentiating cochlear and retro-cochlear lesions even with patients having mind heaving loss.
4. Degree of abnormality in energy integration is proportional to the magnitude of the loss.
5. Abnormal energy integration and recruitment do not always occur together.
6. On the basis of present information Brief Tone Audiometry does't distinguish among various cochlear pathologies.

4.6 Bekesy Audiometry and Loudness Recruitment

In 1947 Bekesy introduced a new audiometer that subsequently gained wide acceptance and application in both research and clinical audiology. The instrument was continuously variable frequency, automatic recording unit. It placed the variables of test tone intensity and test tone duration under the control of the subject. The new instrument permitted the subject to track this threshold by depressing and releasing a signal key, and allowed the measurement of absolute threshold all along the frequency range instead of at octave and midoctave points.

Bekesy audiometry is presently use for its diagnostic value in determining site or lesion as well as for threshold measurement. In the majority of papers concerned with the clinical application of Bekesy audiometry, measurement and description have been confined almost exclusively to the width or amplitude of the audiometric tracing. The distance or width may be expressed either in decibels or in number of threshold crossings over a given frequency span. It was observed that the width of the tracing differed for normals and for certain pathological ears.

Bekesy in his original paper noted that the amplitude became greatly diminished in subjects with hearing loss accompanied by loudness recruitment. For normal ears, the average width remained constant at about 8-10 db over all frequencies. In impaired ears with loudness recruitment, however, tracing width decreased significantly above 1000 Hz and remained unusually small (3 dB and less) throughout the rest of the frequency range. Subjects with conductive impairment and those with non-recruiting perceptive hearing losses yielded tracings similar to normal hearing persons. He assumed that the tracing amplitude represented the first just noticeable difference in loudness and concluded that a reduction in its size and compatible with the presence of an abnormally rapid rate of loudness growth with intensity (in loudness recruitment).

Lundborg in his monograph obtained the Bekesy audiograms on 50 normal's, 25 cases of acoustic trauma and 26 cases of Menier's disease and 21 cases of diverse retro-cochlear lesion. He then classified the audiograms based on the tracing amplitude. There appeared to be a rather precise relationship between type of Bekesy tracing and site of lesion. Markedly reduced amplitude was characteristically present in cases with presumably cochlear lesion (acoustic trauma and Menier's disease) but characteristically absent in cases with retro-cochlear lesion.

In recent years increasing attention has been given to another aspect of the Bekesy tracing, the change in threshold intensity over time as the subject traces threshold at a fixed frequency. Roger, Jerger, Carhat and Lassman and Yantis have shown very little change over time in presumably cochlear lesion, but market progression towards higher and higher threshold intensity over time in retro-cochlear lesion.

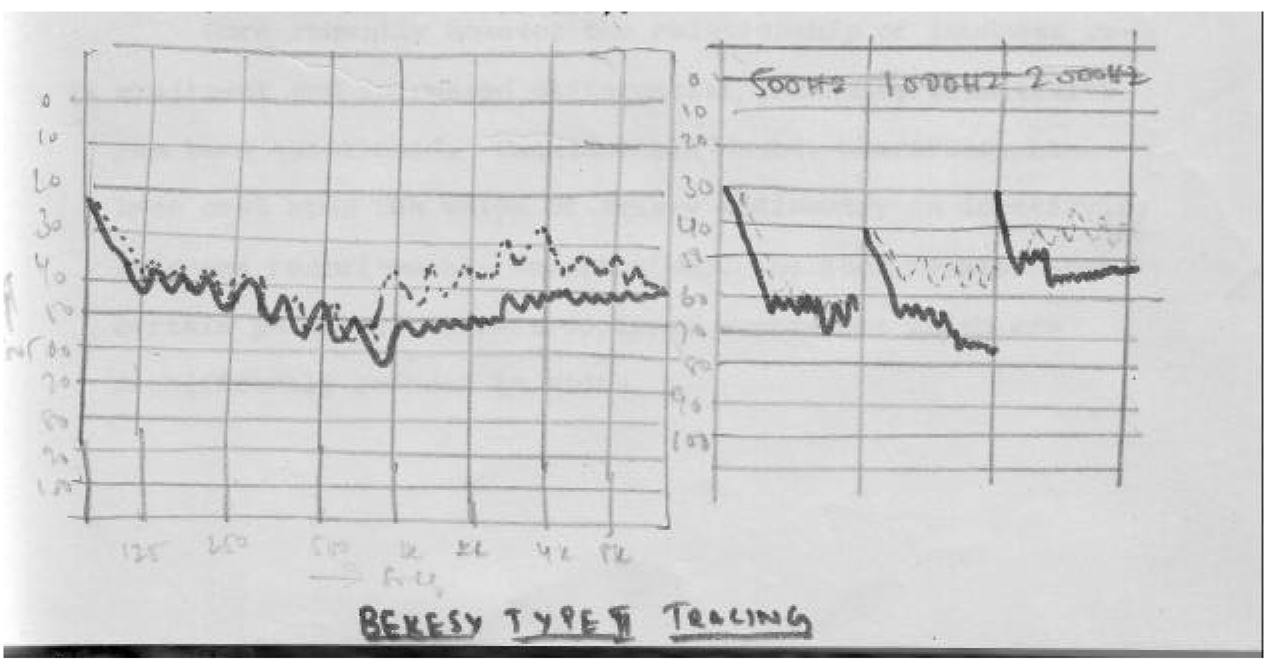
Jerger ( ) classified Bekesy audiograms of 434 patients tested at the hearing clinic of North Western University Medical School over a 3 year period. An initial attempt was made to analyze and score the Bekesy audiograms quantitatively. Various indices such as width of the tracing in dB, number of threshold crossing per octave, difference between tracing width at high and low frequencies, difference between continuous and interrupted tracing widths etc., were evaluated but the overlap between groups appeared to limit the use of these measures.

On the other hand, a quantitative judgment of the patterning or relationship between the interrupted and continuous tracing seemed to have important diagnostic value. There appears to be a unique relationship between continuous and interrupted tracings corresponding to the site of lesion within the auditory system.

Among the 4 types described in cases of cochlear lesion (Menier's disease and noise induced hearing loss) Bekesy Type II predominates. This type II tracings are described by Jerger as follows.

"The continuous tracing drops below the interrupted at high frequencies but never to a substantial extent. The gap seldom exceeds 20 dB and ordinarily does not appear at frequencies below 1000 CPS. Second, the width or amplitude of the continuous tracing is often quite small (3 to 5 dB) in these higher frequencies. This narrowing of the width or amplitude of the continuous tracing is, of course, the classical Bekesy sign thought by many to indicate the presence of loudness recruitment.

In fixed frequency tracing the type II results in quite clear cut. The interrupted tracing, is again horizontal and of normal width, but the continuous tracing drops from 5 to 20 dB below the interrupted, within the first minute; thereafter it maintains a fairly stable level. There is a reliable difference between interrupted and continuous tracing but the difference is relatively small and remains quite constant after the first 60 sec if tracings. Furthermore the difference appears only at mid and high frequencies (i.e., above 500 to 1000 CPS).



Owens after having administered Bekesy audiometry to patients with cochlear lesions and to those with confirmed retro-cochlear lesions recommended the Jerger's description of a type II tracing be expanded. He observed that some of the audiograms in the cochlear lesion group could be confused with other types, particularly type IV. Owen's description of a type II would include those patterns in which the continuous tracing drops below the interrupted at any point in the frequency range and then remains essentially parallel or occasionally may regains the type I tracing.

The observation of Wolfson et al also suggested that modifications are necessary in Jerger's original classifications. These investigators noted that a type IV pattern could be indicated of retro-cochlear deficits or severs cochlear lesions. They found that some individuals with Menier's disease traced a type IV during or just aftwr an acute attack.

More recently however the relationship of loudness recruitment and increased differential intensity sensitivity has been questioned. Considerable doubt, therefore, has been cast upon the value of Bekesy audiometry in identifying loudness recruitment. Nevertheless, the fact remains that certain pathological ears do trace excursions which are significantly reduced in width.

4.7 Acoustic stapedial reflex in determining recruitment

The measurement of the acoustic reflex has been actively pursued in clinical settings for a longer period than any other aspect of the middle ear measurement battery (metz 1946; Klockhoff 1961; Jepsen 1963). This was the most applicable feature of Metz's pioneering efforts to measure the impedance of the ear in a clinical population. Based on the fact that loud signals presented to one ear elicit a bilateral contraction of the stapedius muscle, it became common practice to monitor the impedance change which occurs as a consequence of the muscle contraction. This monitoring has traditionally been performed in the contra-lateral ear (crossed reflex). In recent years instrumentation has become available which permits both the eliciting signal and impedance monitoring to take place in the same ear. This is referred to as ipsilateral (uncrossed) reflex testing. The contra lateral acoustic reflex can be expected to occur at 70 to 95 db SL and 3 to 12 dB lower SL for ipsilateral stimulation in case of normal ears.

In recent years acoustic reflexometry has been used extensively as a clinical tool to indicate the presence of recruitment of loudness. The applicability of this technique as an indirect measure of loudness recruitment is based on the consistent finding that the impaired ear of patients who manifest loudness recruitment yield stapedial reflex thresholds at lower sensation levels than those with normal hearing without recruitment. In general loudness recruitment is assumed to be present if the patient with a hearing loss yields a stapedial reflex at 70 dB SL or less although a less liberal criterion-60 dB SL has been recommended. Presumably the elicitation of acoustic reflex is directly related to the perceived loudness of an acoustic stimulus.

Jerger (1969) reported reflex measurement obtained from the results of sensorineural patients in the age range from 14-59 years. He arrived at the following conclusions:

1. The reflex sensation level declines as a function of increasing hearing loss in patients with loudness recruitment.
2. A sensori-neural loss increases the reflex SL decreases in regular one to one fashion. The relationship is linear and of unit slope. Also for any particular level of hearing los the range of variability among patients is about 40 dB, a range comparable to the distribution of reflex levels in normal ears.

Beedle and Hardford (1973) compared acoustic reflex growth and loudness growth at 500, 1000 and 2000 Hz. Two groups of 10 subjects each were tested: a group with normal hearing and a group with a unilateral hearing loss resulting from endolymphatic hydrops and demonstrating loudness recruitment. Acoustic reflexes were recorded graphically at successive 2 dB increments from the reflex threshold to be sensation level of 16 dB, employing an ascending and a descending approach. ABLB was also performed at 3 sensation level relative to the acoustic reflex threshold. Results indicate that the slope of the acoustic reflex growth function is much greater and more rapid for the normal ears then for either ear of the subjects with unilateral hydrops. Acoustic reflex growth is essentially the same for the impaired ears and the good ears of the subjects with a unilateral hearing loss. These authors question the relationship resumed to exist between loudness experience and the acoustic reflex.

Martin and Brunette evaluated the acoustic reflex as a function of SPL and as a function of loudness using a direct loudness criterion in making the compaction. Fifteen subjects with unilateral sensori-neural hypacusis were tested to determine the sound intensity in the normal ear which is equal in loudness to the intensity eliciting the acoustic reflex in the abnormal ear. The results suggest that the reflex is not a function of either SPL or loudness and therefore, cannot given any absolute information about the presence of loudness recruitment. Low sensation level reflexes observed in hearing impaired patients should not be considered an unequivocal indicant of recruitment.

Metz was the first to suggest the measurement of relative dynamic impedance as a direct objective determination of loudness recruitment. As previously documented by many authors contraction of the intraural muscles in elicited by an acoustic stimulus of 70-90 dB SL in the normal ear. If in the sensori-neurally impaired ear however, the acoustic stapedial reflex is observed at sensation levels less than 60 dB, loudness recruitment is presumed to be present. It is suggested that the stapedial reflex is based on the loudness of the activation signal and thus an abnormally rapid growth of supra-threshold loudness will result in a reflex threshold at a recuced sensation level. Jerger states that the minimal sensation level of the reflex as approximately 25 dB.

Although the Metz test allows for an objective determination of loudness recruitment, remains intensive to the sub-classification of partial recruitment or hyper recruitment as seen with conventional balance results. According to Priede and Coles, the presence or absence of recruitment has limited diagnostic value since most sensori-neural disorders show some recruitment. Most important is the amount of recruitment. Recently Fitzaland and Barton have suggest a formula that may provide a more precise classification of loudness recruitment. They defined

Differential Ration Quotient (DRQ) where as:

$$DRQ = \frac{?? \ ? \ ??? \ ?? \ ? \ ? \ ?}{? \ ? \ ?}$$

A=Acoustic stapedial reflex threshold in the better ear.

X= pure tone threshold in the better ear.

B= Acoustic stapedial reflex threshold in the poorer ear

Y= Pure tone threshold in the poorer ear.

Results indicated that the DRQ will be equal to ‘One’ in cases with complete recruitment, lies between zero and one with partial recruitment, and be greater than one with hyper recruitment. In eleven test subjects the results from the DRQ formula were always in compliance with those obtain from ABLB test.

In previous investigations of acoustic reflex latency, primary concern has been with the latent period between stimulation and response (Metz 1951; Moller 1958; Dallos 1964). Few researches have examined either reflex relaxation following cessation of the stimulus or reflex latency parameters in a cochlear impaired population. Norris’ (1964) study suggested an inability of the impaired ear to respond to a rapid succession of stimulus presentations in the same manner as did the normal ear.

Norris et al (1974) obtained on ordered series of latency measures of the acoustic reflex on 23 normal hearing and 23 sensori-neural hearing loss cases. Five parameters of reflex recordings were considered via latency response; latency from the initial response to the peak of the response; latency from the response peak to the point where the reflex reaches a 95% return to base line; latency from the cessation of the stimulus to the 95% return to base line, and total reflex response time (L2+L3). Statistical analysis revealed no difference between the 2 groups for the contraction or initial portion of the response. However, following the cessation of the stimulus, the sensori-neural group demonstrated a significantly longer relaxation time.

Sieminski. R found no relation between normal's and pathological groups and between ears for both latency and magnitude of the stapedial reflex.

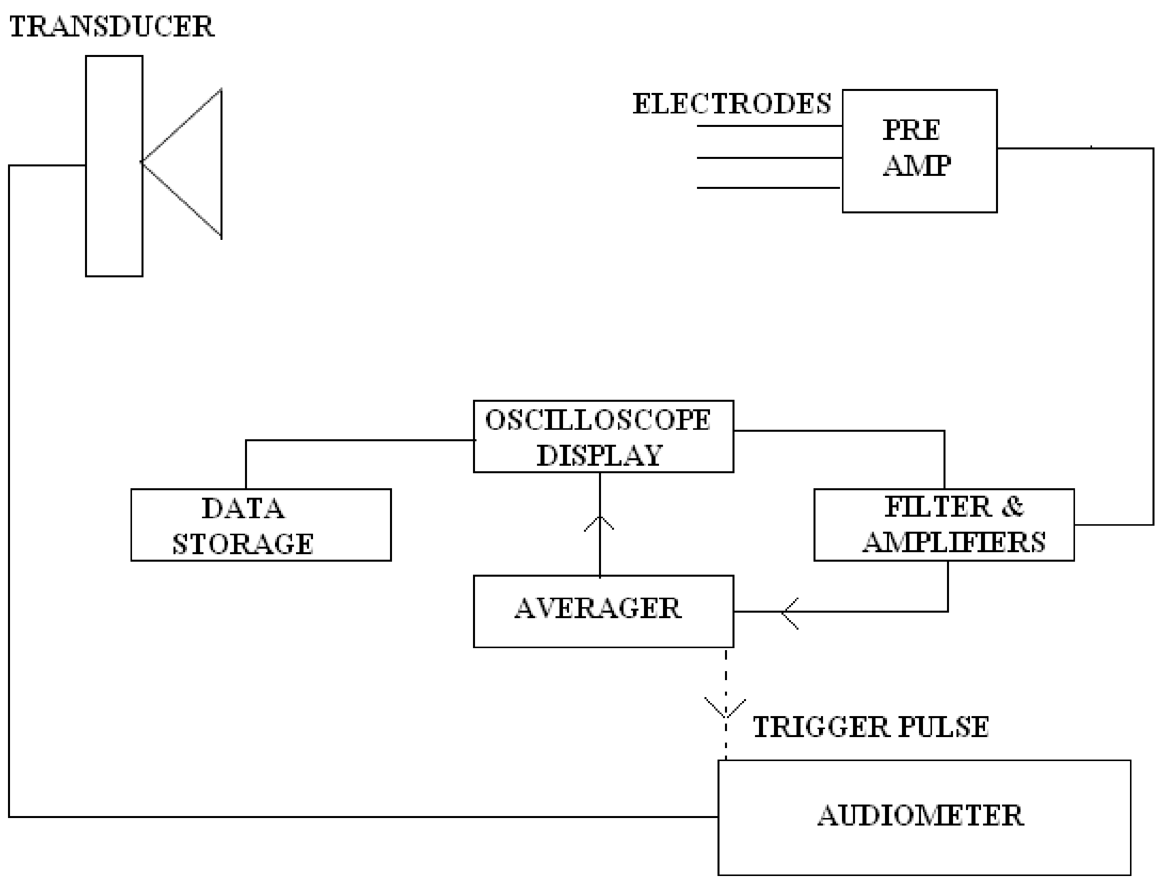
Reflex audiometry is an objective test in the determination of recruitment and is useful in cases who doesn't meet the criterion for loudness balance tests and overcomes the loudness balancing task, on the part of the subject, involved in conventional subjective tests.

4.7 Electrophysiological tests and Recruitment

(i) Average Evoke Response Audiometry

The view is widely held that an abnormal growth of loudness with increase of sound intensity is characteristic of the spiral organ as distinct from defects of the cochlear nerve or higher structures, and the presence of this phenomenon is used in the assessment of certain auditory defects.

Recently, use of the response to auditory stimulation which appears in the electro-encephalogram has been developed as an objective test of hearing sensitivity (Beagley and Knight 1966). An on-line averaging computer is employed to extract the evoked cortical response from a background of electrical noise of physiological origin. Electrical potential obtained between 2 active surface electrodes on the vertex and on an ear lobe, are amplified and averaged for about 60 presentation of a shot pulse of pure tone. It has been show that, after stimulation with moderate intensities, the wave form of this response can be indentified at successively lower levels to within a few decibels of the subjectively lower levels to within a few decibels of the subjectively determined threshold of hearing, especially in the case of adults. With decreasing intensity, the average amplitude of the main components of the evoked response also decreases while the latency increases; this knowledge is of assistance in the objective threshold determinations.



APPARATUS FOR ERA

Development of electrophysiologic techniques of auditory exploration-electrocochleography and the study of slow vertex potentials-provided a new means of studying the recruitment phenomenon. Although the study of recruitment by ECOG has became familiar since the publications of Portman et al (1973) and Eggermount and Odenthal (1974) few authors have shown interest in using the method of the slow vertex evoked auditory potentials. The reasons for this are that the relation between the amplitude of the evoked response and the sound intensity has aroused considerable controversy.

Determination of recruitment by electrophysiological method is an indirect method founded by the curvilinear relation between the amplitude of AER and the loudness. Nevertheless, the general morphology of the curves is perfectly compatible with the conception of recruitment (Fowler 1960, 1963), during the first 30 dB above the threshold, there is an abnormally fast increase followed by a plateau whose level is not significantly different from that of the saturation plateau encountered at high intensities in normal ears. In the presence of recruitment, it is well known that the abnormally rapid increase in loudness with intensity is greatest near the threshold and declines rapidly at higher levels.

Keidel and Spreng (1965) showed that the amplitude of the evoked response varied as a power function of intensity. Davis and Zerlin (1966) supported this relationship. A recent study by Bohe (1975) shows that there are no clear relations between AER and loudness estimation.

Clayton and Rose (1970) on the contrary found no significant difference between the amplitude of responses for normal and recruiting ears.

A. Uziel and S. Seneclause carried out an objective study of auditory recruitment by the method of slow vertex evoked potentials on 18 subjects presenting recruitment at 4 KHz. Evoked potentials were induced by tone burst stimulation of the recruiting ear and recorded by means of an active electrode located on the vertex. For each subject a study was made of the

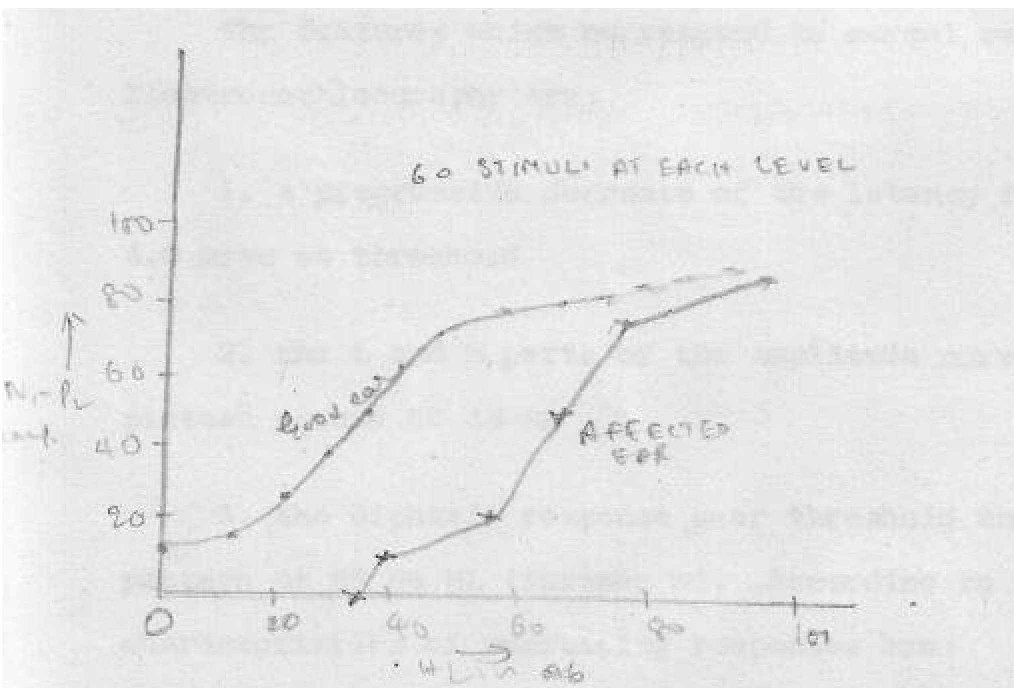
1. Input-output curves of N_1P_2 amplitude and of the latencies of N_1 and P_2 of the evoked potentials as a function of the intensity of stimulation and 2. Of the best estimation of the input-output curve of N_1P_2 to a power function and a logarithmic function by the least squares regression line.

Results of 18 recruiting subjects classified according to their audiometric threshold were statistically compared with those of 9 normal subjects. Relation between the amplitude of the auditory evoked response and the intensity of the stimulation could be expressed nearly equally well by a logarithmic function and a power function. Very significant increase of the slope of least squares regression line in recruiting subjects compared with normal subjects.

Co-efficient of recruitment can be defined as the value of the slope of the least squares regression line representing the variation in amplitude as a function of intensity on a double logarithmic or on a log-linear scale. Calculation of this co-efficient is a valid reflection of the increase in amplitude of AER as a function of the intensity of the stimulation. Difference between normal subjects and recruiting subjects both for mean values and for individual data is highly significant. It is greater in recruiting ears than in normal subjects. There is a curvilinear relation between the intensity of sensation and the amplitude of average evokes response. This serves as a useful method of electrophysiological objectification of recruitment.

An experiment has now been conducted by J.J. Knight and H. A. Beagley (1969) to determine how the amplitude of the evoked response varied with intensity in ears where recruitment of loudness was present. Six persons were tested who suffered from Menier's diseases which affected one ear, while good hearing was present on the other side. Conventional loudness balances were obtained at 1000 Hz and all the subjects showed recruitment. The average amplitude of the N_1

and P_2 components of the evoked response to a 20 msec. pulse of 1000 Hz pure tone presented 160 times at 1.25 sec intervals was measured for the affected and the good ears of each subject. The figure shows the amplitude of on the good ears followed the same pattern of variation with intensity as previously reported with 8 normally hearing subjects tested on 6 occasions. When the affected ears were stimulated, the amplitude decreased more rapidly with reduction of intensity although, at higher intensities, both ears gave approximately equal amplitudes. The results for good and affected ears coincide at approximately 85 dB (I.S.O.) hearing level as shown by the evoked response balance and loudness balance results.



Amplitude of auditory evoked response to 1000 HZ tone in six subjects having recruitment of loudness in one ear. Points shown are averages for the six subjects.

(ii) <u>Electrocochleography</u>

Electrocochleography is a method of recording of the electrical activity of the cochlea and first order, eighth nerve fibres in response to acoustic stimulation. The electrical responses from higher levels of the auditory tract have been deliberately excluded from this definition.

The Clinical use of Electrocochleography is nor restricted to measurement of threshold. Detailed analysis of Elctrocochleography responses show consistent variations in several types of hearing impairment. It is hoped that Electrocochlegraphy will prove useful for diagnostic purposes and will serve the otologist and the audiologist.

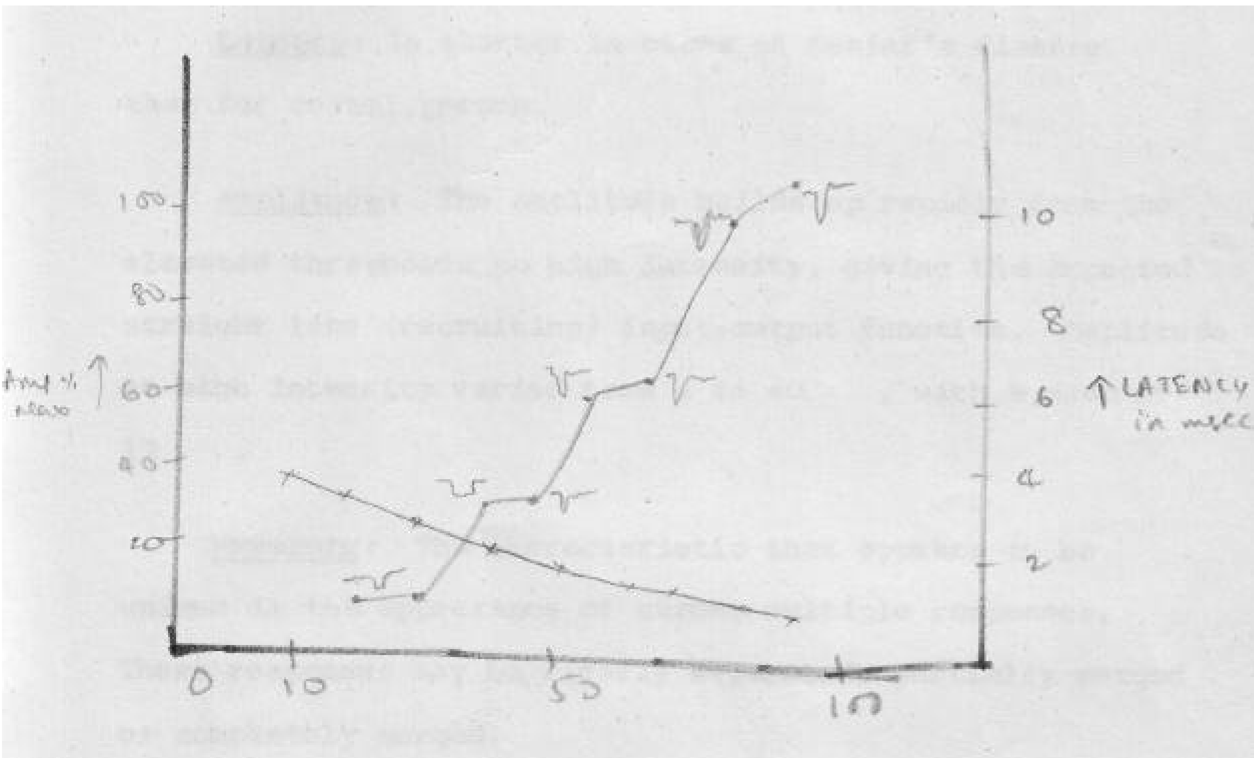
The features which correspond to normal response in Electrocochleography are:

1. A progressive decrease of the latency from around 4.0 msec. at threshold.
2. The L and H parts of the amplitude curve, with the plateau around 50 dB HL.
3. The diphasic response near threshold and monophasic pattern at 85 dB HL (Portman M).

   According to Portman the characteristics of recruiting response are:

   1. The short latency at threshold (2 msec).

2. The high value of the amplitude at 90 dB HL
3. The very fast diphasic pattern of the response.



Characteristics of normal response in electrocochleography

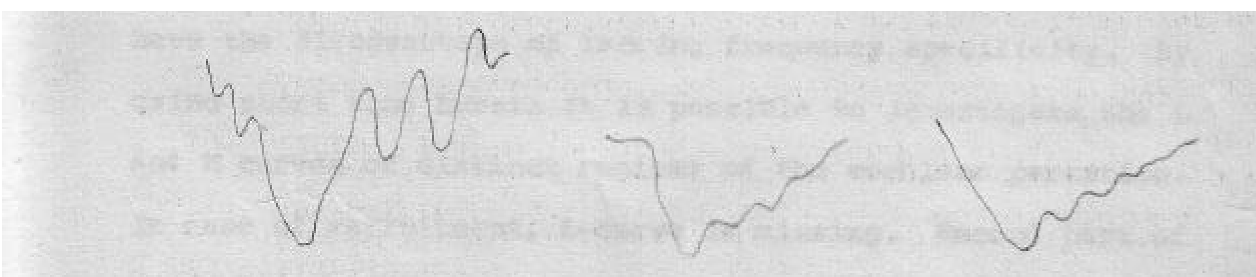
Breckman and Selters give the characteristics of ECOG response in cases of Menier's disease:

Threshold: ECOG threshold vary from audiometric threshold within 10 to 20 dB of behavioral level.

Latency: Is shorter in cases of Menier's disease than for normal person.

Amplitude: The amplitude builds up rapidly from the elevated thresholds to high intensity, giving the expected straight line (recruiting) input-output function. Amplitude at high intensity varied from 4 to 40, with a mean of 17.

Waveform: The characteristic that appears to be unique is the appearance of strong multiple responses. These responses may be clearly separated, partially merged or completely merged.



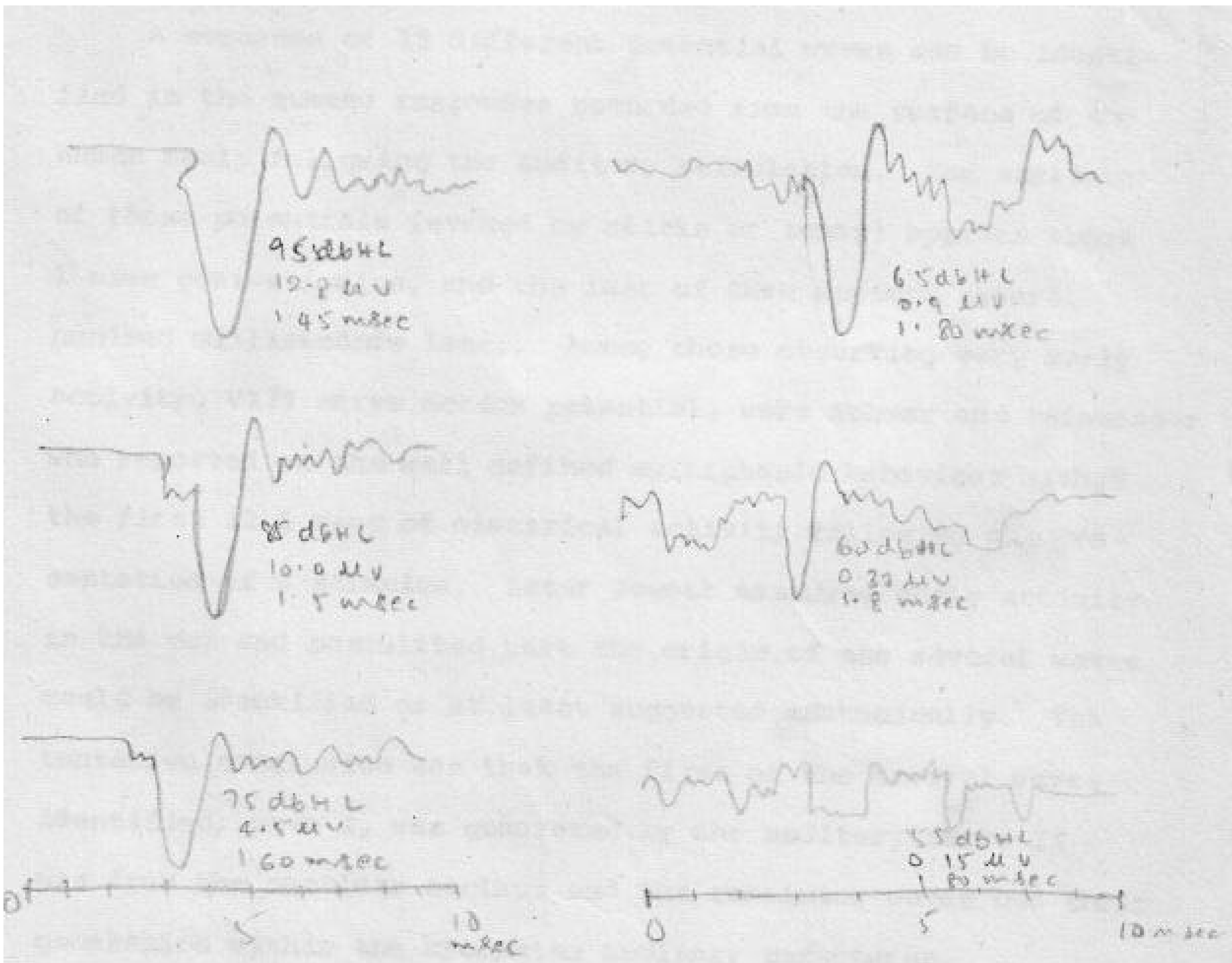
Separated Merging Merged

Width of Action Potential: The value in Menier's cases varies from 0.4 msec to 5msec with a mean of 1.9 msec.

The majority of information on recruitment is provided by the ‘Bordeaux Group’. In general their results indicate that, in the case of recruitment, the threshold for clicks is about 50 dB HL and is associated with a short latency and normal high intensity behavior of the action potential.

It is suggested that in normal ears the input-output curve is composed of an L-curve and an H-curve representing the output of 2 different hair cell populations (Yoshie 1968). In recruiting ears the L-curve having a low threshold (ODB) disappears, while the H-curve (threshold 40 dB) remains unaltered. The composite result is a high AP threshold and a nearly normal high intensity output. Consequently the input-output curve turns out to be steeper than in normal ears.

Eggermont and Odenthal (1974) in investigating a cochlea with high frequency sensor-neural loss the clicks have the disadvantage of lacking frequency specificity. By using short tone bursts it is possible to investigate the L and H curves of distinct regions of the cochlear partition. In case of recruitment, L-curve is missing. Second part of N_1 (N_1 II) is absent. Population II (long latency units) is impaired and does not add to the composite N_1 wave. The AP threshold found in recruiting ears is therefore, essentially the threshold of population I (short latency units) of the specific part of the cochlear partition under study. In general population I is also impaired, resulting in additional threshold difference. At near threshold values, the amplitude of population I increase 10 fold for a 10 dB stimulus increase, the slope being twice as steep as for population II.



Human cochlear action potentials in case of recruitment. The absence of a bimodal N_1 complex and the consistent short latencies along with an abrupt amplitude decrease.

The cochlear Microphonics varies in amplitude in case of recruiting ears but is generally smaller than normal. Rarely does the pseudo-threshold of the CM reach a lower level than the threshold of the AP except in severely deafened subjects. The summation potential is usually small.

(iii) **Brainstem Evoke Response Audiometry**

A sequence of 15 different potential waves can be indentified in the summed responses recorded from the surface of the human scalp following the auditory stimulation. The earliest of these potentials (evoked by clicks or tones) appears about 1 msec. post-stimulus, and the last of them appears several hundred milliseconds later. Among those observing very early activity, VIII nerve action potential, were sohmer and Feinmesser who reported on the well defined multiphase behavior within the first 12.5 msec. of electrical activity following the presentation of a stimulus. Later Jewett measured early activity in the cat and postulated that the origin of the several waves could be identified or at least suggested anatomically. The tentative conclusion was that the first of the several waves indentified, wave I was generated by the auditory nerve II was from the cochlear nucleus and the remaining waves had their generation within the brainstem auditory structures.

Of the seven distinct wave forms which can be indentified, wave V yields much diagnostic information. Clear and stable relationships exist between the intensity of the stimulating signal and the latency of wave v for normal & pathological ears.

BAER measurement has proven to be an effective and objective clinical method of demonstrating recruitment. Hecox demonstrated significant shifts in the latency of wave V among those patients indentified as having recruitment by more conventional audiologic procedures.

Coats, C.A. gave the characteristics of brain stem evoked responses in case of cochlear deficit ears. In these cases they tended to prolong N1 and V latency and to shorten the N1- V interval. Both the N1 and V L-I curves tended to shift upward as 4-8 KHz hearing loss increases with high frequency cochlear deficits the N1-v interval tends to decrease as click intensity is lowered; hence the slight upward slope of the N1-V L-I curve observed in normal's tended to increase with decrease from 4 to 8 KHZ hearing loss.

4.9 Delayed Speech Feedback and Recruitment

There is presently little experimental evidence to show that hearing impaired subjects behave like normal subjects at identical sensation levels of delayed speech feedback. The results of 2 investigators (Butler R.A. and Galloway F.T. 1957); and Elliott C.M. (1955)) suggest that hearing impaired individuals with recruitment will show greater effects on delayed speech feedback than normal listeners, possibly because of the presence of recruitment.

Indeed , theoretical considerations concerning the characteristics of loudness recruitment in pathological ears suggest that individuals manifesting this type of hearing impairment may show reactions to delayed speech feedback at lower sensation levels that either normal's or hearing impaired persons without recruitment. Thus it may be fallacious to expect that all individuals with hearing impairment will behave like persons with normal hearing under exposure to amplified speech feedback.

In view of the above considerations, Harford and Jerger designed an experiment to evaluate the possible contribution of loudness recruitment to the delayed speech feedback effect.

Delayed speech feedback at sensation levels of 0, 10, 20, 30, 40 and 50 dB re spondee threshold was investigated upon 5 groups:

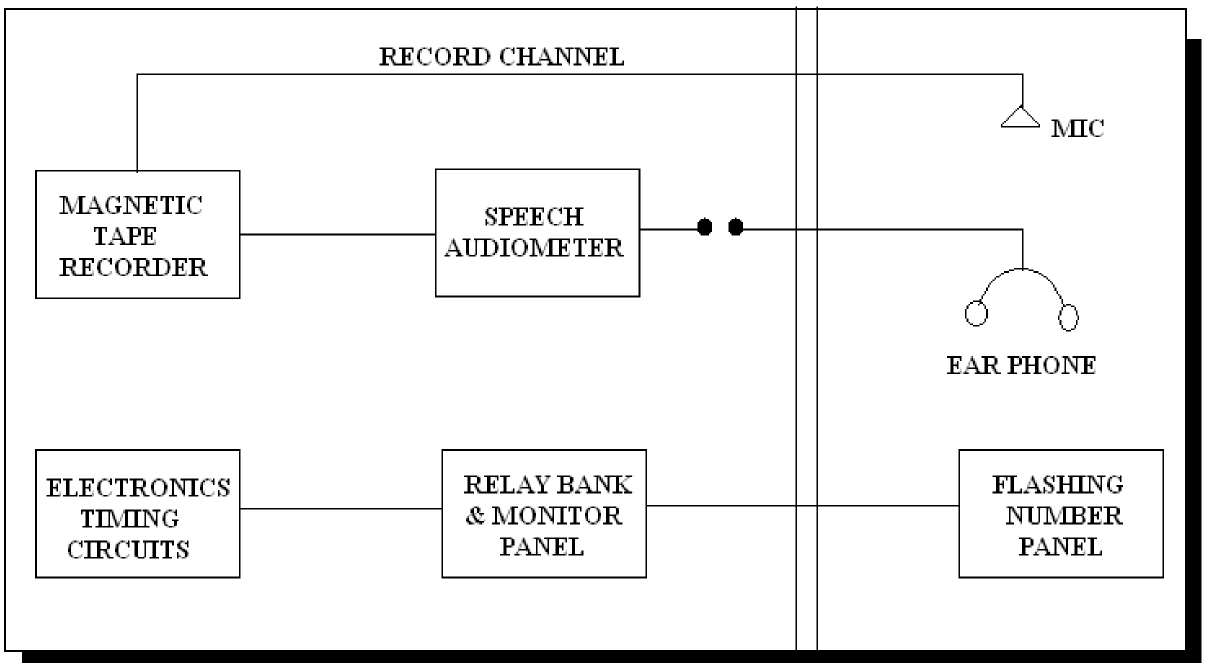
1. A normal hearing group
2. A labyrinthine hydrops group (Presumably with recruitment)
3. A masked-normal-hearing group (with characteristics analogous to recruitment)
4. An otosclerotic group (without recruitment) and
5. A plugged-normal-hearing group (without recruitment).

There were 10 subjects in each groups, overall testing consisted of 3 main procedures:

(a) A brief interview and pure tone testing;

(b) Speech audiometric testing;

(c) Delayed speech feedback testing.



BLOCK DIAGRAM OF THE APPARATUR FOR DAF

The results show a high median error score for hydrops group and masked normal group. Viewing the results within the framework of the experimental design suggests that recruitment does indeed accelerate the function relation feedback effect to sensation level. If the factor of lowered speech discrimination scores in the hydorps group were solely responsible for their performance, a comparable effect would not have been expected in the masked-normal group, where there was no impairment in speech discrimination. The fact that both groups behaved in virtually identical fashion suggests the factor common to both groups, loudness recruitment as the underlying cause.

The unexpectedly high error scores in otosclerotic group are intriguing and yet difficult to explain.

It has been suggested previously that (Hanley 1954) an individual's spondee threshold can be approximated from the lowest intensity at which speech disturbance can be measured under exposure to delayed speech feedback. The results of the present inveastigation indicate, however, That this estimate must necessarily differ depending on whether the subject does or does not have a hearing loss accompanied by loudness recruitment. For example suppose subject manifests evidence of the delayed speech feedback at a HEARING LEVEL OF 70 Db, according to the conventional yardstick, his true spondee threshold would be estimated at no more than 30 dB

The present results indicate. However, that his loss could be as great as 50 or even 60 dB it were accompanied by re cruitment.

Tiffany interprets the present findings to mean that, in matters of adjudication, it may be desirable to estimate the actual loss closer to the feedback response level than the behavior of normal s would imply. Not to do so would be err in favour of the defendant in a damage suit.

4.10 The Aural overload Test

The aural overload test is basede on the electrophysiologic principle that cochlear microphonics become non- inear and reveal harmonic distortion when the intensity of a tons exceeds 50 dB above threshold. These harmonies can be measured psychophysically with an exploring tone. The objective is to Ascertain the minimum intensity level necessary to produce harmonic distortion as a consequence of overloading.

According to Lawrence and Yantis (1956) when the inner ear is involved the thresho ld of overload is lowered and the range restricted. In every case with loudness recruitment, there was a lowering of ove rload threshold. They suggested that detecting the harmonics is the actual measure of the ear's distortion characteristics and is a qualitative picture of

Distortion . In 4 cases of VIII nerve lesions, they reported that the range from threshold to point of overload was usually greater than that of cases with cochlear involvement.

In the untrained ear, the overtones can best be detected by the use of an exploring tone which beats with the harmonic of the fundamental when the frequencies and intensities of the two are close together. The determination of the level of a tone above an individual's threshold at which the 2nd harmonic of this tone can first be detected indicates the beginning of non linear distortion and is indicative of shortened dynamic range typical of an unhealthy condition in the inner ear. It is of course true that individual vary conasiderably in their sensitivity to various tones and this can be caused by many factors but the only established
Source of influence for a shortened dynamic range is the inner ear.

Technique : 1. Audibility threshould for the fundamental tone to be used (1 KHz/2 KHz) and for second harmonic of the fundamental tone (2 KHz/4 KHz) are determined.

2. The fundamental frequency is then set on one pure tone oscillator so that when presented to the ear under test it will be 70 Db above audibilty threshold for that tone.

3. On a second oscillator, the exploring tone frequency

is made to differ from the frequency of the sermonic, of the fundamental by 4 CPS and then adjusted at 60 d B above the subject's threshold for second harmonic.

4. The tones are then mixed and switched to the subject's ear under test. In most cases he will hear beats with only a slight adjustment of the exploring-tone intensity. If beats beats are readily perceptible .

5. Upon hearing beats (establishing aural overload) the levels of both tone are commonly attenuated until the subject says the beats are no longer heard. This level of the fundamental is recorded and considered to be the threshold of aural overload which may be expressed in terms of any predetermined level, above 0.0002 dynes /cm2 above audiometric zero or above threshold of audibility for individual subjects. In the latter case, the number of decibels from threshold of audibility to threshold of aural overlod is the range of linear response.

Aural overload test and recruitment

One indication for inner ear involvement is the presence of loudness recruitment. It has been suggested that a reduced dynamic range as found in cochlear ears is indicative of loudness recruitment.

Sokolmski applied a technique for measuring aural harmonics to the diagnosis of recruitment . He presented a 500 CPS fundamental tone to the ear by air conduction and an exploring tone of 1003 CPS by bone conduction, thus producing beats in the ear of the subject. He found that in normal subjects beats appeared at a sensation level of 45 to 50 dB in the fundamental tone. However, in perceptive losses with recruitment he found the overload threshold to be only slightly higher than the intensity of 500 CPS fundamental tone, provided, the extent of loss exceeded 45 to 50 dB.

Opheim and Flottorp also found that in 70 of 73 ears with monaural hearing loss and evidence of recruitment, markedly restricted ranges were found.

Out of 17 abnormal ears with cochlear involvement tested with aural overload test at 1000 CPS , Lawrence and yantis were able to administer either ABLB, MBFLB test 12 of them. Of these 11 had definite recruitment and 1 partial recruitment. Mean dynamic range in the 11 ears with positive recruitment was only 11 dB at this frequency. At 2000 CPS, 16 out of 24 ears could be give the loudness balance test, 13 of these showed definite recruitment and 3 demonstrated it partially. The mean dynamic range was 16 in the 13 tested with positive recruitment. Thus those ears having definite recruitment consistently had an overload threshold much lower than the normal mean.

Djupesland and Flottor (1970) reported a direct relationship among results of the ABLB test , Metz test and the aural overload test. The advantages of the aural overload test over the other 2 test are:

1. The aural-harmonic test unlike the ABLB can be readily applied to both unilateral and bilateral hearing losses.

2. Metz test requires the absence of middle ear pathlogy. Such is not the case for the aural overload test.

Herbert and young (1966) reported that there was no significant difference in point of overload between recruiting and non-recruiting presbycusis. Increased aural overload was related more to age than hearing level. Herbert and young suggested that the increases aural overload in the absence of abnormal adaptation in presbycusis may be considered a measure of mechanical cochlear dysfunction.

Determination of the level at which a tonal or speech stimulus becomes uncomfortable was first advocated by Watson (1944) as an assessment of the recruitment phenomenon.

Hence the aural overload tecilitates in the establishment of recruitment in ears otherwise not amenable to such determination, and that the recruitment phenomenon is intimately related with an abnormally restricted range of linear response as well as cochlear involvement.

4.11 Critical Band Width Recruitment

The critical band width is an empirical phenomenon is defined as the band width at which a number of psychoacoustic functions change abruptly (Scharf 1970), threshold, loudness, masking, musical consonance, phase sensitivity and the abillty to discriminate partials in a tone complex. It is commonly compared to an acoustic filter, the width of this filter being a measure of the frequency selectivity of the ear (zwicker 1975, Evans 1975).

When either a wide band noise or narrow band noise is used as the masking signal, the results of auditory studies can be explained solely on the basis of the masking phenomena. A study by palva, Goodman and Hirsh (1953) tended to show that masked a differential diagnosis. In their study of noise audiometry they overlooked the possibility that, even though masking increases at the normal rate for recruiting ears, the S/N ratio at threshold could still be different in recruitment from that in normal ears.

Miskolcy –Fodor (1954) and Harris and Meyers (1958) have shown that one measure of auditory time, the range through which an ear can summate energy is shorter for recruiting than for normal ears. This shortened time characteristic of recruiting ears suggests that some corresponding band width will be increased (since time constants of the performance system are directly and inversely related its band width).

In patients with sensori-nearing loss, indirect measurements of critical band width have given conflicting results (palva et al 1953, jerger et al 1960, Simmon 1963).

Direct measurement s have been few but seem to indicate a widening of the critical band in at least patients with a sensorineural hearing loss.

De Boer (1959) Reported a widening of the CB in both masking and threshold experiments in a patient with sensorineural hearing loss.

Scharf and Hellman (1966) and Martin (1974) using the method of loudness summation of tone complexes, found evidence for a widened CB in pooled data obtained from small groups of patients with cochlear hearing loss.

De Boer and Bouvmuster (1974) examined the critical band by threshold measurements of a pure tone as a function of the bandwidth of a gap in a wide noise signal. In patients with a sensori-neural hearing loss, having loss, having at least a cochlear component, the date might indicate a critical band only in some of them. A similar inconsistent relationship between permanent sensori-neural hearing loss critical band width, measured by the method of loudness summation, has been reported by per Bonding,

Per Bonding used a modified version of the method of loudness summation, developed for clinical critical band estimation. The stimuli are noise bands centered around 1 KHz . The standard procedure includes 1. Determination of the sensitivity curve: the loudness difference between broad band noise and narrow band noise as a function of the level. for clinical use this function is necessary for evaluation of the level with the most rapid growth of loudness with band width, 1.e., the optimum level for sharp determination of the critical band width.

2. Determination of the critical band function, 1.e., the difference in sound pressire level required for equal 1oudness of the test noise band and the reference as a function of the band width.

3. Critical band estimation by a mathematical model.

The results of the pooled data in 20 patients with presbycusis indicated a normal critical band width both in patients with hearing loss less than 50 dB HL and in patients with hearing loss greater then or equal to 50 dB. The normal loudness difference between broad band noise and narrow band noise was resuced at all levels, except the highest, giving rise to very flat CB function. Recruitment seem to be reflected in the shape of the sensitivity curve at the highest level in recruiting ears the loudness difference between broad band noise and narrow band noise is smaller than in non recruiting ears.

In patients with Menies's disease (Bonding 1978 C) a normal critical band was found in both groups with hearing loss so dB and 50 dB HL.

During a slight temporary salicylate-induced hearing loss, the normal loudness difference between broad band noise and narrow band noise was markedly reduced at all levels, except the highest. The band width appeared to be louder in 9 out of 16 subjects, to a degree roughly proportional to the degree of hearing loss.

Simon G.R. conducted a study to explore 1. The width of the critical band at a frequency where recruitment is present in impaired cochlas as compared with normal ears.

2. Relation between the size of the critical band width and log time.

3. Accuracy and reliability of such measures of the CBW.

The following 2 hypothesis formed were.

1. In a wide band wide noise the width in decibel of the critical band is greater at frequencies where recruitment is present in impaired cochleae than at same frequencies for normal ears.
2. The Width in decibel of the critical band should increase as the time through which temporal summation can occur decreases. Extent to which the summation is restricted for recruitment ears should be related to the increase in critical band width.

Measurements were made at 1 KHz and for specified signal durations and spectrum levels for white noise.

Results of this study shows that at a frequency where recruitment is presest (4 KC) the width in decibel of the CB is greater for the listener with recruitment than for the normal hearing listener at the same frequency , further that a restricted time through which the ear can summate energy exists for the cochlear impaired ears as compared to normal hearing ears. Results obtained at 4 KCPS for an 800 msec signal duration indicates that if a patient's critical band width is 3 dB greater than that of normal hearing subject the patient shows evidence of recruitment.

Relation between critical band width level and log time

Was the for both the normal hearing and recruiting ears Temporal summation did not occur beyond 100 msec for recruiting group. Where as summation continued for normal hearing group up to 200 msec.

Bonding (1979) Performed the critical band estimation in eleven patients with acoustic neuroma. The normal loudness difference between brood band noise and narrow band noise was reduced at all levels except the highest .Judged as single individuals, 9 of the 11 patients had normal critical band the pooled data indicae a normal critical band, both in patients with hearing loss 50 dB HL and in patients with hearing loss 50 dB HL.

The average reduction in the maximum 1600 is less Pronounced in patients with acoustic neuroma than in patients with menier's disease, but a large overlapping of the maximum 1600 from the 2 groups does occur. Thus the loudness summation method can't be used safely to differentiate between cochlear and retrocochlear lesions.

A significant difference between recruiting and nonrecruiting ears is present in the sensitivity curve at the highest test level applied 95 dB HL. Still, exceptions from this rule were found and no safe conclusions regarding the use of the method of loudness summation as a monaural recruitment test can be drawn based on present material.

4. 12 Cross modality matching in the study of abnormal loudness function

A cross matching procedure between loudness and vibrations, which proved to be useful in normal psychophysical research was applied by Thalmann R (1965) to the study of abnormalities of the loudness function. It was found that with few exceptions, comparatively inexperienced subjects could match loudness to vibration in a consistent way, in both normal and abnormal loudness conditions. The first part of the experiment was performed on normal subjects In whom recruitment was induced artificially by ipsilateral masking.

The pseudo-recruitment demonstrated by loudness balance was almost exactly duplicated by a match of vibration to loudness. In the second part of the experiment , cross matching was performed on patients with different types of hearing loss. In a selected sample of unilateral conductive deafness the vibration matching functions of the 2 ears had the same shape slope but were displaced relative to erach by an amount equal to the loss in the affected ear. In a selected sample of inilateal deafness of the recruiting type the vibration

Matching function in the normal ear was the same as in normal listeners, but the recruitment of the Impaired ear was also evident in the match of vibration to loudness.

CHAPTER V

SPEECH INTELLIGIBILTTY AND RECRITMENT

5.1 Speech discrimination and recruitment

Persons suffering from perceptive deafness commonly find it difficult to understand amplified speech and their understanding of speech is easily destroyed by completing speech or noise. It has been suggested by Huizing (1948) and others that recruitment which distorts the subject's perception of amplitude relationships among the acoustical elements of speech is a sufficient cause for loss of intelligibility. The analogy that abnormal loudness relationships created by recruitment are transposed to the normal dynamic span of hearing, suggests that recruitment can decrease both intelligibility and resistance of intelligibility to acoustical interference.

Miskolczy –Fodor (1958) reported that the relationship between signal duration and loudness for deaf subjects with recruitment was same as for normals.

Hallpike and hood (1959) found that measured recruitment curve did vary in shape, but that for many subjects they were essentially linear over the dynamic rang which we are concerned.

Some authors have indicated auditory discrimination acores may indicate the presence of recruitment. Attempts have been made in obtaining discrimination scroe and discrimination loss in cases with recruitment. (Huizing and Reynrjes 1950, Eley and willams 1951). In recruiting cases the discrimination reaches a maximum of considerably less than 100% and then never higher even though the intensity is increased further.

Hirsh (1952) reported Davis (1948) finding the low maximum articulation score in patients with perceptive recruiting loss.

Hirsh, Palva and Good man (1954) found a reliable relationship can exist between low discrimination scores and recruitment if the hearing loss is greater than 20 dB.

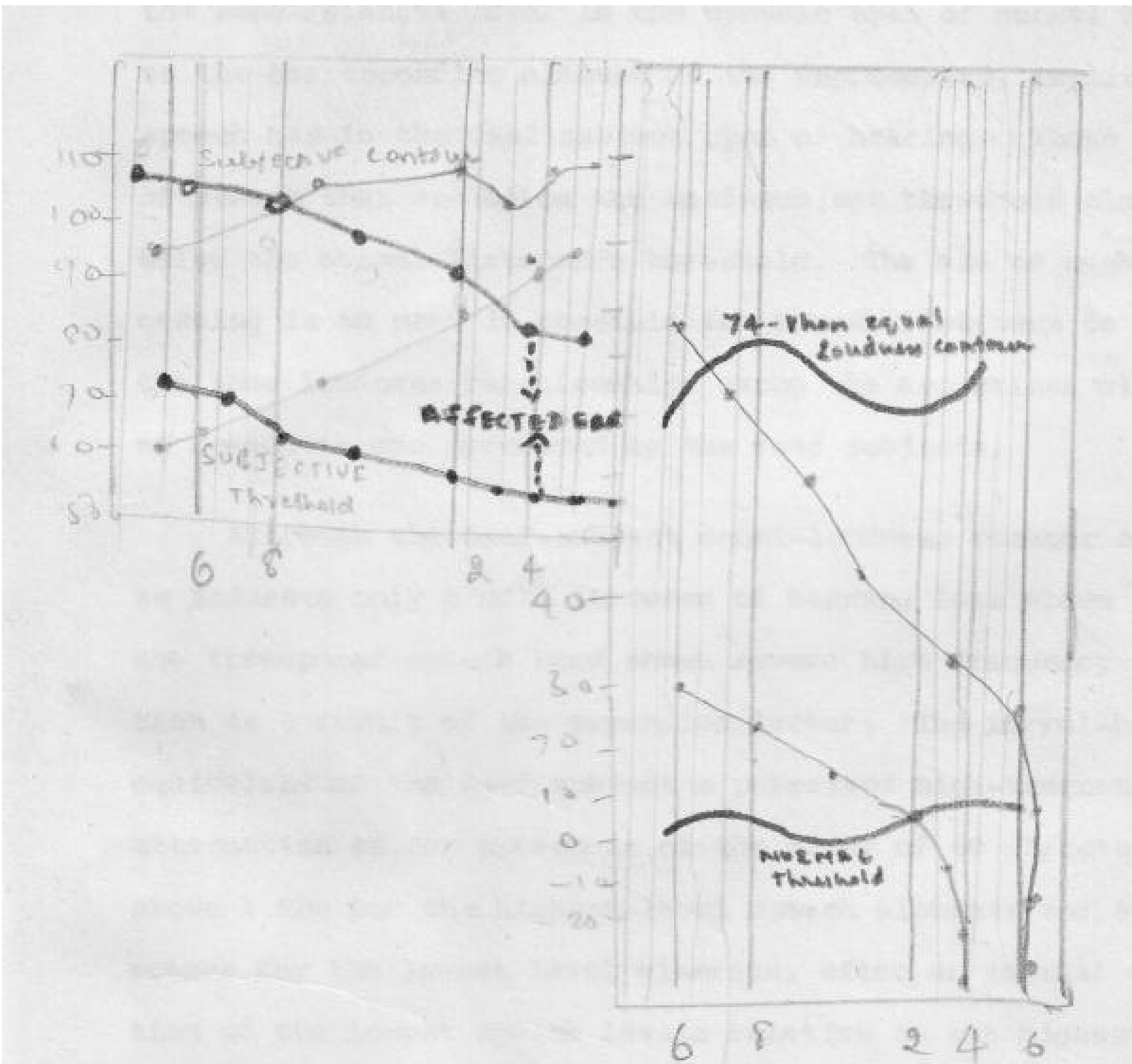
Pestalozza and shore (1955) however, report this not to be true of older individuals and suggest that phonemic regression may be present in the absence of cochlear damage. They indicated that the absence of recruitment might indicate Lesions in the spiral ganglion cells or nerve fibres which are most commonly responsible for prebycusis. These authors also suggest that since discrimination scores in presbycusis are generally poor, tests for recruitment should be used as the deciding factor in diagnosis.

Jerger (1973) conducted in interesting investigation concerning the effect of loudness recruitment on auditorty discrimination capabilities among the elderly. Acoustic reflex measurements were utilised to determine the presence of recruitment as opposed to traditional loudness balance procedures. Discrimination scores were compared for 2 groups of 12 elderly individuals, Each with presbycusis, one group demonstrating recruitment and one without. A third group of subjects, as controls, consisted of 12 young persons with recruitment. Three measures measures were compared between groups (1) The pure tone audiogram (2) The P.B. max score (3) The sensation level of the acoustic reflex. Presence or absence of recruitment was defined by the sensation level at which the acoustic reflex was elicited for frequencies of 500, 1 KHz, 2 KHz and 4 KHz. Acoustic reflex levels and conduction thresholds for the three groups were not substantially different. Jerger concluded that "the disproportionate loss in speech discrimination in aging patients is apparently not strongly related to the loudness recruitment phenomenon".

Villchur (1973) in his experiment with 6 deaf subjects provides an indirect support for the analogy that recruitment can reduce both intelligibility and the resistance of intelligivilty to acoustical interference. In his experiment speech was processed to compensate rather than simulate recruitment.

The speech signal was subjected to frequency – dependent amplitude compression followed by treble emphasis – the reverse process used here for the analogy, so that deaf subjected could perceive the same loudness relationships among speech elements as are perceived by normals. Speech recognition was improved significantly for the 6 subject and readjustment of the processing characteristics by each subject for maximum speech intelligibility usually confirmed the calculated values as reasonably accurate. The reference level of the deaf subject equal loudness contour is related to that of the 74 phon contour by way of the deaf subject preferred listening levels for speech. The reduced span between the thresholds and equal loudness contours of these subject reflects their recruitment.

Morgan and plantier (1963) Report that in phonetic discrimination tests of hearing for speech, Patients with recruitment habitually distort certain phonemes, particularly vowels. These phonemes are easily identified by non-recruiting patients with similar hearing losses. Four lists of words (French) were prepared to be read to the patient at 20 dB above his threshold of discrimination. These included one list containing vowels in the middle frequencies, two lists containing vowels in the 3000-4000 CPS range and one list containing voiceless consonants with characteristic frequency zones above 4000 CPS. There were 10 words in each list. This test is not recommended for congenitally deaf children. but the authors recommend it for adults, both for efficiency and for ease of administration. The disturbed zones of the vowel sound are within the range of the second formant.



Projection of the Amplifies speech from the abnormal to the normal span of hearing in deaf subjects.

In the figure a projection of the amplified speech from the abnormal to the normal span of hearing is seen. The distorted amplitude relationships within this projected speech band are created by subjecting the speech signal to frequency-dependent volume expansion followed by high frequency attenuation. Each audible element of the processed speech has the same relative level in the dynamic span of normal hearing as the corresponding element of the unprocessed, amplified speech has in the deaf subject span of hearing. Those elements of speech that are below the deaf-subject threshold also fall below the normal listener's threshold. The aim of such processing is to make it possible for normal listeners to perceive the same loudness relationships among the acoustical elements of speech as are perceived by the deaf subjects.

Although the deaf-subject equal –loudness contour appears to indicate only a mild increase of hearing loss above 1 KHz, the transposed speech band show severe high frequency attenuation as a result of the expansion factor. The normal –hearing equivalent of the deaf subject's perceived high-frequency attenuation as for speech is of the order of 40 dB/octave above 1 KHz for the highest-level speech elements and 60 dB/ octave for the lowest level elements, after an initial attenuation of the lowest speech levels relative to the highest speech levels of 28 at 1 KHz.

Since recruitment expands the difference in loudness between low-frequency high amplitude vowels and high frequency, low-amplitude consonants, speech is subjected to effective high-frequency attenuation even if the subject's hearing impairment does not become greater high frequencies.

The effect of signal duration on the sensation of loudness analogy by villchur are:

1. The effect of signal duration on the sensation of loudness In deaf subjects which may be different from the corresponding effect in normal.

2. Non-linear recruitment in deaf subjects, i.e., recruitment varies in degree over the amplitude range and.

3. Abnormal susceptibility of deaf subjects to forward making, as reported by Gardner (1947) which could change their instantaneous loudness response in vowel-consonant sequencies.

Villchur (1974) conducted 2 experiments to test the hypothesis that the processing can also simulate the abnormal loudness relationships perceived by the deaf subjects in a complex speech signal.

1. Comparison of expansion or equalization processing with masking.

2. Evaluation of recruitment processing by unilaterally deaf subjects.

Experiment : 1 : The loss hearing included in a normal listener by masking is accompanied by recruitment, as pointed out by steinberg and Gardner (1937) the subject's loudness response increases toward normal as the amplitude of the sound stimulus is increased above his new threshold. The recruitment curve associated with masking approaches the curve of normal loudness growth asymptotically, but the departure from linearity of the induced recruitment, measured in the present subjects by loudness-balance tests, was relatively minor over the intensity range significant to the masked speech. The noise-deafened ears were considered to be reasonable substitutes for deaf ears with linear recruitment so far as loudness relationships in speech are concerned.

The quality that characterized the expanded signal-an exaggeration of the normal dynamics of speech and an absence of high frequency elements – was reported by the subjects (2 normal hearing subjects) as clearly evident in the masked speech.

For both subjects, the masked and processed signals remained similar to each other after speech interference was added. The relative loudness of the interfering signal did

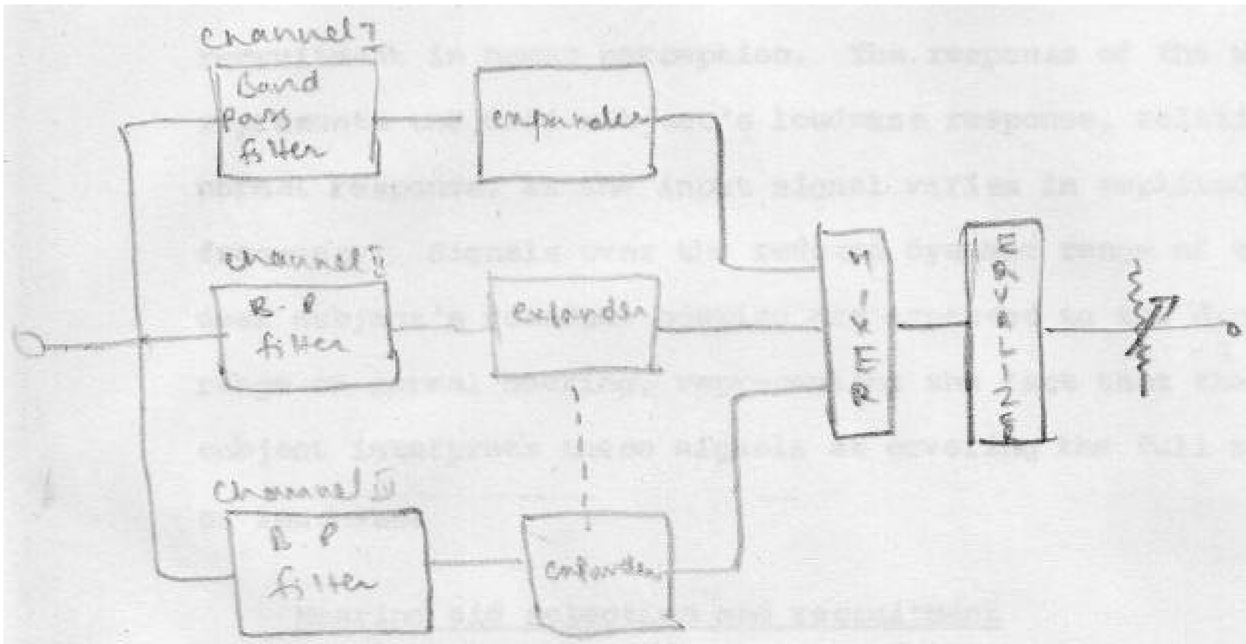
Appear greater in the processed signal as predicted but only part of the time and by a large amount.

The expanders and equalizers worked well, so far as speech quality is concerned in representing the infinite bank of effective expanders created by the induced recruitment. Speech interference was not grossly misrepresented by the processor possibly because the random time pattern of speech proceeded enough staggering among the instantaneous levels of simultaneous voices.

Experiment 2 : Simulated recruitment processing calculations were made for four subjects with unilateral, nonconductive deafness accompanied by recruitment. The calculation were made on the basis of the relationship between the subject's normal-ear and impaired-ear hearing spans in the same way as in the masking experiment, using threshold and loudness-balance measurement. The subject were asked to make judgments' of the similarity or difference in quality between samples of speech heard in each ear. The impaired ear was presented in turn with unprocessed speech, speech subjected to recruitment processing calculated for the subject and processed speech whose characteristics had been readjusted by the subject to make the sound in his two ears as alike as possible.

The results show that at all subjects rated unprocessed speech in the normal ear as different in varying degree from unprocessed speech in the impaired ear all subjects rated the final processed speech in the normal ear as similar or very similar to unprocessed speech in the impaired ear.

The similarity between left and right ear signals was not evaluated by objective intelligibility tests while a valid simulation of recruitment would duplicate the effect of exaggerated loudness relationship on in intelligibility it would not take into account perceptive impediments to speech recognition other than recruitment. Intelligibility scores for the impaired ear could thus be considerably lower than scores for the processed speech without invalidating the simulation of loudness relationship. Further agreement between processed and impaired ear scores would not validate the simulation because processed speech intelligibility can be reduced by signal processing unrelated to the subject's perceptive observations.



Signal processor to simulate for normal listeners the subnormal loudness relationships perceived by a deaf subject with recruitment. The processor is an electrical analog ue of recruitment. The response of the model represents the deaf subject's loudness response relative

The circuit is proposed as an electrical analog of recruitment in human perception. The response of model represents the deaf subject's loudness response relative to normal response as the input signal varies in amplitude and frequency. Signals over the reduced dynamic rang of the deaf subject's residual hearing are expanded to the dynamic rang of normal hearing, representing the that the deaf subject interprets these signals as covering the full rang of loudness.

Hearing aid selection and recruitment

Word discrimination tests have been used in audiology clinics in the evaluation of hearing aids for the past three decades. In the hearing aid evaluation the first decision to be made is whether or not the client is a candidate for a hearing aid, provided the client reports significant communicative difficulty and provided further that he is motivated to objectively evaluate the effects of amplification in personally significant communication situations, then very few hearing impaired individuals are not prospective hearing aid candidates. This should not be construed to mean that all these people can successfully adjust to or benefit from amplification. The question which must be answered is whether the client is able to communicate more effectively with without the

Hearing aid. Now let us see the role played by recruitment in the hearing aid evaluation.

Since patients with recruitment exhibit poor auditory discrimination and ears with poor discrimination do not benefit from hearing aid, it can be concluded that cases with sensorineural hearing loss exhibiting recruitment are not good can didates for hearing aid.

Aural overload test in the selection of hearing aid

It is often recognized that those patients having the greatest difficulty in the effective use of hearing aids are those who have perceptive type of hearing loss. It is reasonable to account for this at least in patients with inner ear involvement because of the characteristically restricted dynamic range of response to sound in these individuals. Aural distortion is introduced at a much lower level above threshold than in those with a conductive loss or in those it is presumed with an involvement of the auditory nerve alone. It would seem therefore that the aural overload test may be of value in discerning those ears which could overload at an abnormally low level. If the threshold of aural overload at an abnormally aid is greater than the threshold of aural overload then the hearing aid is not useful for that individual. Thus important information would be added to results obtained by

Other techniques employed to determine the prognosis for the use of electronic amplification.

Siqnal processing to simulate hearing aid compensation

The ‘recruitment analogy’ given by vullchur (1974) can be used as a tool to help analyze problem in hearing aid design. The hypotheses derived must be tested in the real world of deaf subjects. Ideal signal processing for a hearing aid designed to compensate recruitment would counteract precisely the expansion and treble attenuation of the recruitment model.

The hearing aid processor will restore near normal in tensity relationship to the transposed speech with means that if the recruitment analogy is valid the circuit will process normal, amplified speech, the transposed speech is reprocessed to an imperfect copy of the normal speech band while for the deaf subject the elements of normal speech, are processed to corresponding relative levels within his hearing

If only the equalization of hearing aid circuit is used without compression then the low amplitude speech elements are not amplified to useful levels. More high frequency emphasis could be used to bring the top of the speech band to its normal, relative level, but treble boost without compression must be used sparingly in a hearing aid. High amplitude treble sounds in the real environment may be amplified to levels that are intolerably loud for the deaf subject, whose discomfort levels are likely to be either normal or lower then normal. The low amplitude elements of speech are brought in to correct loudness relationships with high amplitude elements of the same frequency, but severe treble attenuation remains. The normal hearing equivalent of this attenuation is of the order of 30 dB/octave above 1 KHz.

SUMMARY

Recruitment is usually defined as an abnormally rapid growth of loudness as intensity is increased. Although, an increasingly intense signal is perceived as increasing in loudness, the ear with exhibits recruitment shows a more rapid increase in loudness than would normally be expected.

There are many theories explaining the mechanism of loudness recruitment but none is generally accepted.

The phenomenon of recruitment is seen in the following auditory pathologies.

1. Conductive hearing loss (conductive recruitment)
2. Cochlear pathologies

(i) Menier's disease
(ii) Noise induced hearing loss
(iii) Prebycusis
(iv) Ototoxicity
(v) Sudden hearing loss

3. Retrocochlear hearing loss (co-existence of recruitment and abnormal tone decay).

4. Brainstem lesions.

The are many tests described for detecting the presence of recruitment.

1. Loudness Balance procedures.

   (i) ABLB (Fowler 1928)

   (ii) MBFLB (Reger 1936)

2. Loudness Discomfort level test

3. Difference limen in testing recruitment

   (i) SISI (Jerger 1959)

4. Brief tone audiometry

5. Bekesy audiomentry (Bekesy Type III, Jerger 1937)

6. Acoustic stapedial reflex

   (i) Metz recruitment test

   (ii) Differentianl ratio quotient

   (iii) Reflex relaxation index

7. Electrophysiological tests

(i) Average evoked response audiometry

(ii) Electrocochleography

(iii) Brainstem evoked response audiometry

8. Delayed speech feedback

9. Aural overload test

10. Critical band width in recruitment

11. Cross modality matching test in cases of recruitment.

The presence of recruitment reduces the speech discrimination ability of an individual and hence in a factor to be considered in hearing aid selection.

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