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# A comparison of the Bekesy-type test with Roger's monaural test of Fowler's binaural test for recruitment

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Thesis

# A COMPARISON OF THE BEKESY-TYPE TEST WITH REGER'S MONAURAL TEST OR FOWLER'S BINAURAL TEST FOR RECRUITMENT

Submitted by

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# CHAPTER I

# INTRODUCTION

The detection and measurement of auditory recruitment has become an important aspect of audiology both in the clinic and in research. It is used by Otologists and Audiologists as an aid in diagnosing type of deafness, locating site of pathology and evaluating effectiveness of hearing aids. No standardized test has been adopted to date although many different methods have been devised. These methods fall into two major classifications: a loudness balance measurement and a difference limen measurement.

## Purpose

The purpose of this investigation is to compare the Bekesy-type test with Fowler's Binaural Test or Reger's Monaural Test for recruitment. The specific objective being to determine whether the difference limen as measured by the Bekesy-type audiometer can discriminate between recruiting, questionable recruiting, and non-recruiting ears as shown by the loudness balance method.

## Justification

The study of recruitment through loudness balance and difference limen testing is part of the proposed audiological assessment in the research project, "Hearing and Communication as Related to Gerontology." The resulting information will aid in achieving the overall aim of the project, that is, the extensive and complete exploration of the effect of the aging process on hearing and communication in an elderly group of people.1/

Another indication of research need in the recruitment area was suggested by Palvo who states:

> "I have felt that before conclusions are drawn from the width of excursions in a self-recording audiogram, a good deal more of validating work must be done. This is the case with the parallelism of recruitment and small tracings as well as with other experimental tests which very conveniently can be done with the self-recording audiometer.2/

Scope

One hundred and sixty-seven subjects between the ages of 50-90 were tested with the Bekesy-type test. Each ear was considered a separate test. Along with the Bekesy test the subject was given a Reger monaural balance test or a Fowler Binaural Test for recruitment.

Definition of Terms Used

Recruitment: Recruitment is a phenomenon in which the loudness of tones appears to increase more rapidly than

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1/"Hearing and Communication as Related to Gerontology," Public Health Service, National Institutes of Health, Research Grant No. 3-B-9083, Bethesda, Md., 4-6, Ocotber, 1957.

2/Tauno Palvo, "Self-Recording Audiometry in Hearing Evaluation," Volta Review, 60:158, April, 1958.

normal when the growth of loudness is related to intensities above threshold. It is usually associated with a perceptive loss due to inner ear involvement.3/

Lorente di No's reported a neurological explanation which aids in understanding recruitment:

> "If a number of hair cells in the ear or a number of fibres in the cochlear nerve are missing, the tones will appear to be weaker in intensity when near threshold stimuli 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 with the limiting intensity the cochlear fibre or the cells of the cochlear nuclei, so that the cerebral cortex will receive the same number of impulses per second from both ears and will perceive the tone delivered to the diseased ear as strongly as the tone delivered to the normal or less affected ear.4/

Difference Limen: "The smallest detectable difference between two intensities that can be discriminated is referred to as the difference limen(DL)."5/

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3/Ira J. Hirsch, The Measurement of Hearing, (New York: McGraw-Hill Book Company, Inc., 1952), p. 341.

4/R. Lorente de No., in discussion on Fowler, E. P. Fowler, "Diagnosis of Diseases of the Neural Mechanism of Hearing by the Aid of Sounds well above Threshold," Tr. Am. Otol. Soc., 27:2-7-220, 1937, cited by J. D. Harris, H. L. Haines, J. C. K. Myers, "Loudness Perception for Pure Tones and for Speech," A.M.A. Arch Otolaryng, 55:113, February, 1952.

5/I. J. Hirsh, T. Palvo, A. Goodman, "Difference Limen and Recruitment," A.M.A. Arch Otolaryng, 60:526, November, 1954.

In recruiting ears, the difference limen for intensity is smaller than in normal or non-recruiting ears.[6]

6/Ibid.

## CHAPTER II

## REVIEW OF THE LITERATURE

### Loudness Balance Testing

In 1924, Pohlman and Kranz reported the first observation of the recruitment phenomenon. They observed that when the threshold of a range of decreased acuity was attained it took comparatively little additional energy to cause the deficiency to seemingly disappear completely.[1] Later in 1928, Fowler noted during an audiometer test of a patient with a normal left ear but with a right ear with a loss of approximately 40 db near 4096 cps, that:

> "...comparative loudness showed that the loudness of tones (near 4096) of from 10-25 sensation units above the threshold in the left (non-affected ear) appeared the same loudness as 5 sensation units above the threshold in the right (affected ear)."[2]

In 1936, Reger reported that individuals with high frequency hearing losses experienced as abnormally rapid increase in loudness when the intensity level was increased above the threshold value at which the loss existed. Such individuals with raised auditory thresholds could detect

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1/A. G. Pohlman and F. W. Kranz, "Binaural Minimum Audition in a Subject with Ranges of Deficient Acuity," _Proc. Soc. Exper. Biol. and Med._, 21:335-337, 1924.

2/E. P. Fowler, "Marked Deafened Areas in Normal Ears," _Arch. Otolaryng_, 8:152, 1958.

smaller increments in intensity than the normal ear at intensity levels the same number of db above the respective threshold of each.[3] Beginning in 1936, Fowler published a series of papers concerning this abnormal rapid increase in loudness in patients with neural deafness. He was the first to apply the term "recruitment" to this phenomenon. Fowler's investigations led him to the conclusion that the presence or absence of recruitment constituted a clinically useful method of differentiating between conduction deafness and neural deafness. The method was called the Alternate Binaural Loudness-Balance Test and has been adopted widely as a tool for both clinical and experimental investigation of the loudness function in normal and abnormal ears. The procedure employed is that of matching the loudness of a given tone in the two ears. This method, however, is limited in its application since it requires the patient to have a normal ear for comparison.[4]

3/N. Reger, "Difference in Loudness Response of the Normal and Hard-of-Hearing Ear at Intensity Levels Slightly Above the Threshold," Ann. of Otol., Rhin. and Laryng., 45:1029-1039, December, 1936.

4/S.N. Reger, op. cit., 1032.

Reger developed a monaural loudness-balance test based on the results of studies concerning equal loudness level comparisons by the normal ear. These results showed that the ear is able to compare and equate quite accurately the loudness of two pure tones which differ in frequency.[5] He devised a measure in which the loudness at the impaired frequencies is compared with the loudnessof the normal frequencies at threshold and at set intervals above threshold. The usefulness of the monaural loudness-balance test is that it is not necessary for the patient to have one good ear with which to compare a poor ear. The only limitation of the test is that the patient must exhibit normal or relatively normal hearing for at least one frequency so that this frequency can serve as the standard to which the sensation of loudness at other frequencies is compared.[6] Both loudness-balance tests are plotted on an audiogram enabling convenient appraisal and comparison.

## Difference Limen Testing

The difference limen (DL) test is based on the conclusion that the difference limen of the recruiting ear is

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5/Ibid.

6/Hayes A. Newby, Audiology, (New York: Appleton-Century-Crofts, Inc., 1958), p. 174.

less than that of the normal or the non-recruiting ear especially at threshold levels. This test enables a quantification of results since it is possible to set up a scale of comparison by means of which the degree of recruitment can be expressed. The scale is based on the difference limen for normal ears expressed in terms of decibels or fractions of decibel.[7/]

Several different techniques of DL testing were developed. Luscher and Zwislocki[8/] introduced a method which involves the alternate presentation of two tones, identical in frequency but varying in intensity at about 40db above threshold. The difference between the tones is gradually lessened and the subject is required to signal when he no longer hears the tone variations. The difference between the tones (in percentage of pressure) is then recorded and used as a measure of DL size. Denes and Naunton[9/] refined this method by asking the subject to report which of two sounds is louder thereby eliminating the pulsation effect.

7/Ibid, 172-174.

8/E. Luscher, "The Difference Limen of Intensity Variations of Pure Tones and Its Diagnostic Significance," Proc. Roy. Soc. Med., 43:1116-1128, December, 1950.

9/P. Denes, and R.F. Naunton, "The Clinical Detection of Auditory Recruitment," J. Laryng. and Otol., 64:375-398, July, 1950.

The sounds are presented separately rather than in the continuously alternating method of Luscher and Zwislocki. The Denes and Naunton technique begins with two tones which are considerably separated in intensity. Then the tones are gradually brought closer together until the subject reports them as equally loud. Jerger[10] also made a refinement on the Luscher method. He improved on it first, by using the ascending method and secondly, by using 15 db above threshold as his level of presentation.

In 1947, Bekesy developed an audiometer which measures difference limen simultaneously with the absolute intensity. He describes the principles behind this technique as follows:

> "....an audiometer has been built in which the intensity of the tone increases continuously as long as a signal button is released. The subject determined his own threshold by pressing the button until the tone is perceived, then releasing the button until the tone disappears, pressing the button again till the tone reappears etc. etc. In this way the tone oscillates around the threshold of the subject the whole time and the amplitude of the oscillation is a measure of the difference limen for intensity at the absolute intensity threshold.

10/J.F. Jerger, "A Difference Limen Recruitment Test and Its Functional Significance," Laryngoscope, 62:1316-1332, December, 1952.

The audiometer thus measures this difference limen simultaneously with the absolute intensity threshold."11/

Bekesy points out that since the test tone is always in the vicinity of the threshold little time is lost in the presentation of subliminal stimuli. One advantage in using this technique is that it can be used with any type of unilateral or bilateral hearing impairment. Another lies in the fact that it can be carried out easily since it is fully automatic except for the instructions, thereby making it an objective rather than a subjective measure.

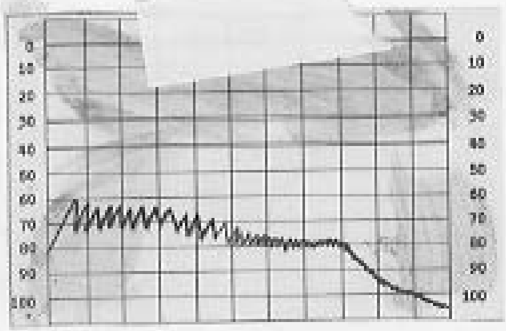
Figure I represents a Bekesy audiogram. In the top curve there is no great change in DL with frequency, the shape of the curve is as usual and represents a case without recruitment. In the lower curve, on the other hand, there is a sharp decrease in the amplitude of the intensity oscillations, the DL drops at the higher frequencies. The lower curve illustrates recruitment.

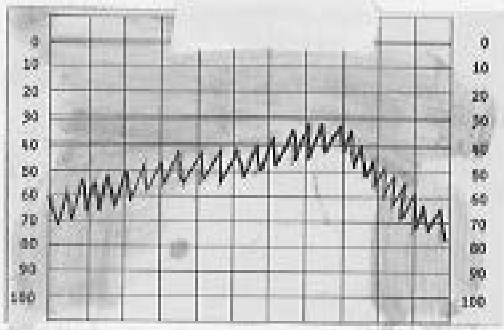
11/G.V. Bekesy, "A New Audiometer", Acto Otolaryng., 35:412, 1947.

Figure I

Comparison of Non-Recruitment and Recruitment on a Bekesy Audiogram

No Recru



In the lower curve, the intensity range about the threshold value is "average" over the frequency levels at which the acuity is normal but is markedly reduced at the frequency levels at which the maximum hearing loss exists. The reduced intensity range is due to the fact that the patient experienced a disproportionately rapid increase in loudness as the intensity was raised above the threshold value. This represents the presence of recruitment since the intensity difference limen near the threshold is more acute in individuals who have recruitment.[12/]

Bangs and Mullins,[13/] Reger and Kos,[14/] and Lundborg,[15/] have all implied that a small difference limen, diminished excursions in the threshold audiogram, and recruitment are equivalent. It is important to note that in normal ears, the DL increases somewhat between 100 and 1000 cps and then keeps constant to about 4000 cps. Above this frequency it

12/G.V. Bekesy, op. cit., 411-422.

13/J.L. Bangs and C.J. Mullins, op. cit., 4-5.

14/S.N. Reger and C.M. Kos, "Clinical Measurements and Implications of Recruitment," Ann. of Otol., Rhin., and Laryng., 61:810-823, September, 1952.

15/T. Lundborg, "The Bekesy Audiogram in the Differential Diagnosis Between End Organ and Nerve Fiber Deafness," Acta Oto-laryng., Supp. 99:81-110, 1952.

drops again and reaches the original value at 10,000 cps. Bekesy states that this relationship agrees with the Kingsbury curves of equal loudness.[16]

The literature reveals that several studies have investigated the problem of determining a DL measurement denoting recruitment. Bekesy did not state any definite limits of threshold variability for cases to be classified as recruiting when introducing his method.

Lundborg reported that perceptive loss of hearing with recruitment in the Bekesy audiogram indicates cochlear localization of the damage; if recruitment is absent, with great probability, retrocochlear localization is indicated. In this study he classified Bekesy audiograms into four types. Type I represents a normal DL (without recruitment) with even, wide oscillations corresponding to 6 to 9 decibels with extreme limits of 5 to 20 decibels. Type IV is defined as a curve with an obvious decrease in the difference limen to no more than 2 to 3 decibels in the higher frequency ranges. Type II differs from Type I in that it shows a tendency to recruitment, that is, where the decibels decrease somewhat in certain higher frequency ranges but the decrease is neither pronounced nor

16/G.V. Bekesy, op. cit., 418-419.

progressive. Type III moreclosely resembles Type IV and exhibits a decrease from between 9-6 decibels successively to 5 to 3 decibels which is described as moderate recruitment.17/

The clinical material supported Lundborg's criteria fairly well--all twenty-five cases of acoustic trauma and practically all twenty-six cases of Meniere's disease belonged to the fourth group (complete recruitment). However there is a question of the recruitment function in each case since no loudness-balance tests was used for comparison.

Newby designated the Bekesy difference limen measurement as follows:

> "The patient with normal hearing or with non-recruiting type of loss will have thresholds which fluctuate a minimum of 4 to 6 db, that is, there will be a difference of at least 4 to 6 db from the highest position of the pen to the lowest at any frequency. For a patient who has recruitment, however, the excursion of the pen will be limited to I to 2 db. In other words, the patient with recruitment is able to detect minor changes in intensity at threshold, and he will push and release the push button more frequently than will the subject who does not have recruitment."18/

17/T. Lundborg, op. cit.

18/Hayes A. Newby, op. cit., 176-177.

A more recent study was done by McLay in 1959 who found that when recruitment is present the DL range is less than 3 db; when it is not present the range is between 6 and 10 db. He also reported a comparison of loudness balance test-with Bekesy testing using 52 audiograms showing unilateral deafness. In 41 the agreement between tests was identical. In the other 11, 9 showed recruitment by the loudness balance test and not by the Bekesy. He concluded that if the Bekesy DL is reduced, recruitment is almost certainly present. If the DL is not reduced, the result is not so certain but recruitment is probably not present.[19/]

Palva pointed out an important aspect concerning the DL as measured by the automatic audiometer. He agreed that small variability and recruitment are parallel but not because the audiometer is a true measure of DL but because it is a measure of the variability around the patient's threshold. Therefore small variability would indicate that the audiability goes up rapidly; whereas large variability would indicate a clearly slower relation between the two.[20/]

Data was reported on 39 patients belonging to various diagnostic categories. On the basis of loudness-balance

19/Kenneth McLay, "The Place of the Bekesy Audiometer in Clinical Audiometry," Journal of Laryngology, 73:460-465, July, 1959.

20/Tauno Palvo, "Recruitment Tests at Low Sensation Levels," Laryngoscope, 66:1519-1540, December, 1956.

tests the cases of recruiting perceptive deafness were further subdivided in asymptotic, straight line and delayed recruitment groups. The majority of the asymptotic group showed excursion amplitudes of less than 3 db. However in some cases in this group it was found that the excursions were more than 5 db and parallel to those in the other diagnostic categories. Most of the cases in the straight-line recruitment group showed normal threshold excursions (larger than 5 db) while practically all delayed recruitment cases showed normal excursions (between 5 and 15 db). Small threshold excursions were most readily demonstrated at 4000 or 6000 cps. They could also be easily obtained at 2000 or 1000 cps but rarely if the frequency was lower. On the basis of these results Palva felt that the Bekesy-type audiometer can never replace ordinary audiometry combined with Fowler's or Reger's balance test since many cases showing recruitment by Loudness-balance testing failed to show it in the form of small threshold variability.[21] Palva also reported these findings in a 1957 report.[22]

Landes supports Palva's theory of threshold variability

21/Tauno Palva, loc.. cit.

22/Tauno Palva, "Self-recording Threshold Audiometry and Recruitment," A.M.A. Arch. Otolaryng., 65:591-602, June, 1957.

in his investigation of automatic audiometry. His study involved using a loudness attenuator which varied the voltage of a stimulus so as to produce unequal increments in intensity with equal increments of rotation. Ten normal ears and twelve recruiting ears were given automatic audiometric tests at seven discrete frequencies so that results obtained could be compared with similar data obtained through more standard means.[23]

The four general conclusions drawn from the study were:

1. Taken as a group, recruiting ears give narrower threshold excursions than do normal ears in response to standard automatic audiometry.
2. Notwithstanding significant group differences it is difficult to separate individual recruiting ears on the basis of standard automatic audiometry.
3. The use of the loudness attenuation in automatic audiometry provides a sensitive test of recruitment, using the criterion of a narrowing of threshold excursions from middle to high frequencies.
4. In automatic audiometry subjects respond to growth of loudness rather than to DL's.[24]

Recruitment and Presbyacusis

The literature reveals conflicting opinions concerning the actual presence of recruitment in presbyacusis which is defined by Fowler as:

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23/Bernard A. Landes, "Recruitment Measured by Automatic Audiometry," A.M.A. Arch Otolaryng., 68:685-695, 1959.

24/Ibid., p. 695.

> "...a diminishing hearing acuity incident to advancing years due to a progressing loss of function mainly in the neural apparatus of hearing (peripheral, central or cortical, singly or combined, continuing or intermittent)."[25]

Schuknecht[26] and Saltsman[27] feel that in the epithelial atrophy type of presbyacusis the loss of hair cells and the loss of spiral ganglion cells are closely parallel. Accordingly, neither the neural atrophy type nor the epithelial type of presbyacusis can show recruitment as they lack the prerequisite for the production of this phenomenon, which is a near-normal number of ganglion cells. If, however, an older person with high tone deafness does show recruitment, it may be assumed that his aging has not affected his ganglion cells and that his hearing loss is due to hair-cell damage. Harbert and Sataloff[28] came to a similar conclusion in that recruitment is generally not present in presbyacusis except in certain types where the organ of Corti is primarily involved.

25/E.P. Fowler, "Presbyacusis: The Aging Ear," Ann. of Otol., Rhin. and Laryng., 68:764, September, 1959.

26/H. Schuknecht, "Presbycusis," Laryngoscope, 65:402-419, 1955.

27/M. Saltzman, "Presbycusis," Arch. Otolaryng., 66:67-69, 1957.

28/F. Harbert and J. Sataloff, "Clinical Application of Recruitment and Masking," Laryngoscope, 65:113-123, March, 1955.

Pestalozza and Shore reported a study primarily concerned with the possibility of differentiating on the basis of audiometric tests the various types and locations of lesions that produce deafness in old age. In a group of 24 aging subjects in which a monaural loudness-balance test was performed, 50% showed no recruitment, 30% partial recruitment, and 20% almost complete recruitment. The authors point out that the absence of recruitment is in good agreement with those histological findings that indicate spiral ganglion cells and nerve fibers as the most common lesions responsible for hearing loss in presbyacusis.29/

Fowler, in a 1959 investigation, summarizes his theory concerning presbyacusis in the following manner:

> "There is a notion that recruitment is not present in presbyacusis but with few exceptions I have found it present. In instances where patients complain about the annoyance of loud environmental sounds, this is one sign of recruitment. When there is a neural hearing loss but no sensed recruitment of loudness I explain it by lesions central to Corti's organ, some neural impendance in the pathways in the brain stem, a feedback, or some deficiency in the receptor mechanisms in the cortex. Any of these might prevent a patient from sensing a recruitment of loudness even though there was a recruitment of potentials in Corti's organ."30/

29/G. Pestalozza and I. Shore, "Clinical Evaluation of Presbyacusis on the Basis of Different Tests of Auditory Function," Laryngoscope, 65:1136-1163, 1955.

30/E.P. Fowler, op. cit., p. 773.

# CHAPTER III

## PROCEDURE

The data available for this study was originally gathered as part of the field study survey "Hearing and Communication as Related to Gerontology" which is taking place at The Age Center of New England, Inc. The survey consists of investigating the aging processes of hearing in an elderly group of relatively healthy volunteers in order to provide a solid foundation on which future, more specific, investigations or research studies may be based. The routine audiological assessment of all subjects includes the following recruitment tests: (1) Reger's Monaural and Fowler's Binaural Loudness Balance tests which are given when possible; (2) A Békésy-type test at both fast and slow speeds. All tests were given by two examiners and were given at two separate sessions.

### Subjects

One hundred and sixty-seven subjects between the ages of 50 and 90 were available for this study. The age distribution is shown in Table I.

TABLE I

AGE DISTRIBUTION

| Age | No. of Members |
|---|---|
| 56-60 | 9 |
| 61-65 | 18 |
| 66-70 | 37 |
| 71-75 | 53 |
| 76-80 | 26 |
| 81-85 | 15 |
| 86-90 | 7 |
| Over 90 | 2 |
| | Total 167 |

However, of the 334 ears available for study, the sample tested by the binaural or monaural loudness balance technique was reduced by one hundred and twenty-one years for the following reasons:

| | | |
|---|---|---|
| Failed to complete test: | 23 | ears |
| Could not be tested: | 94 | ears |
| Unreliable: | 4 | ears |
| | 121 | ears |

Consequently, the population was reduced to two hundred and thirteen ears (334 minus 121) due to the results of loudness balance testing. The sample was further reduced because the slow Bekesy tests of 22 ears were invalid; that is, at one or more octaves the hearing in each of those ears was better or worse than could be registered within the limits of the audiogram. The total number of ears used in the slow speed is one hundred and ninety-one (213 minus 22). Thirty-three fast Bekesy audiograms were also invalid reducing the sample tested at this speed to one hundred and eighty ears (213 minus 33).

## Instrumentation

The Bekesy-type test was measured with a Grason-Stadler Automatic Audiometer (model E800). A continuous sweep frequency technique was used with the stimulus attenuated in two decibel steps. The pure tone covered a frequency range of 100 to 10,000 cycles per second. The test was presented at two speeds: 2.4 decibels per second (slow speed); 4.8 decibels per second (fast speed). The total testing time for the slow speed was 6 minutes and 40 seconds; the speed of the graph paper was .57 centimeters per second. The total testing time for the fast speed was 3 minutes and 20 seconds with the graph paper moving at a rate of .114 centimeters per second.

The loudness balance tests were made using the Beltone 15-A Clinical Audiometer. All testing took place in a Grason-Stadler sound-proof booth in which the ambient noise levels at a normal pure tone test pattern for all frequencies above 256 cps. were below 30 decibels.

## Bekesy Testing

The Bekesy-type audiometer was carefully calibrated before each test. After seating the subject in the sound-proof booth, the tester held the Bekesy signal switch and a pair of earphones in her hand as she demonstrated and verbalized the following instructions

> "You are going to hear a tone. When you hear the tone, press the button; when the tone disappears, release the button."

If the subject was confused, the examiner repeated the directions until the subject stated that he understood. The examiner then placed the earphones on the subject. The automatic audiometer was located in an adjoining chamber and had a sound-proof window into the testing area which enabled the examiner to observe the subject during the testing. A sample test pattern was presented to the better ear initially, and if the subject appeared to be following the directions, the test was started. When necessary, thermal noise was delivered through the second channel of the audiometer for masking purposes.

The audiogram was obtained as follows: A pure tone stimulus of controlled intensity, varying continuously and unidirectionally in a frequency over a given range, was presented to the subject through a suitable transducer. The subject controls the intensity, increasing and decreasing it so that it will cross and recross his threshold. His adjustments are continuously recorded on an audiogram card which moves as the frequency of the stimulus tone changes. The resulting amplitude of the oscillations, according to Bekesy, is a measure of the difference limen for intensity at the absolute threshold. The audiometer therefore measures the difference limen simultaneously with the absolute threshold.1/ Figure II represents an audiogram of a Bekesy-type test.

Fowler's Binaural Loudness Balance Testing

Threshold measurements were obtained for both ears at all frequencies with the pure tone audiometer. The frequencies that showed at least a 20 db loss in the poor ear was chosen to be balanced for loudness in the good ear.

The tester gave the following instructions:

> "You are going to hear two tones, a first tone and a second tone. Tell me which is louder, the first or second, by saying aloud either 'first' or 'second'."

The intensity of the chosen frequency was increased 20 db above the threshold of the good ear and the tone was presented

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1/G. V. Bekesy, op. cit., 412.

FORM HL-4
1-57

Figure II

GRASON-STADLER COMPANY
FOR USE WITH AUDIOMETER TYPE E-800

SEX______ AGE______ No.______

NAME______

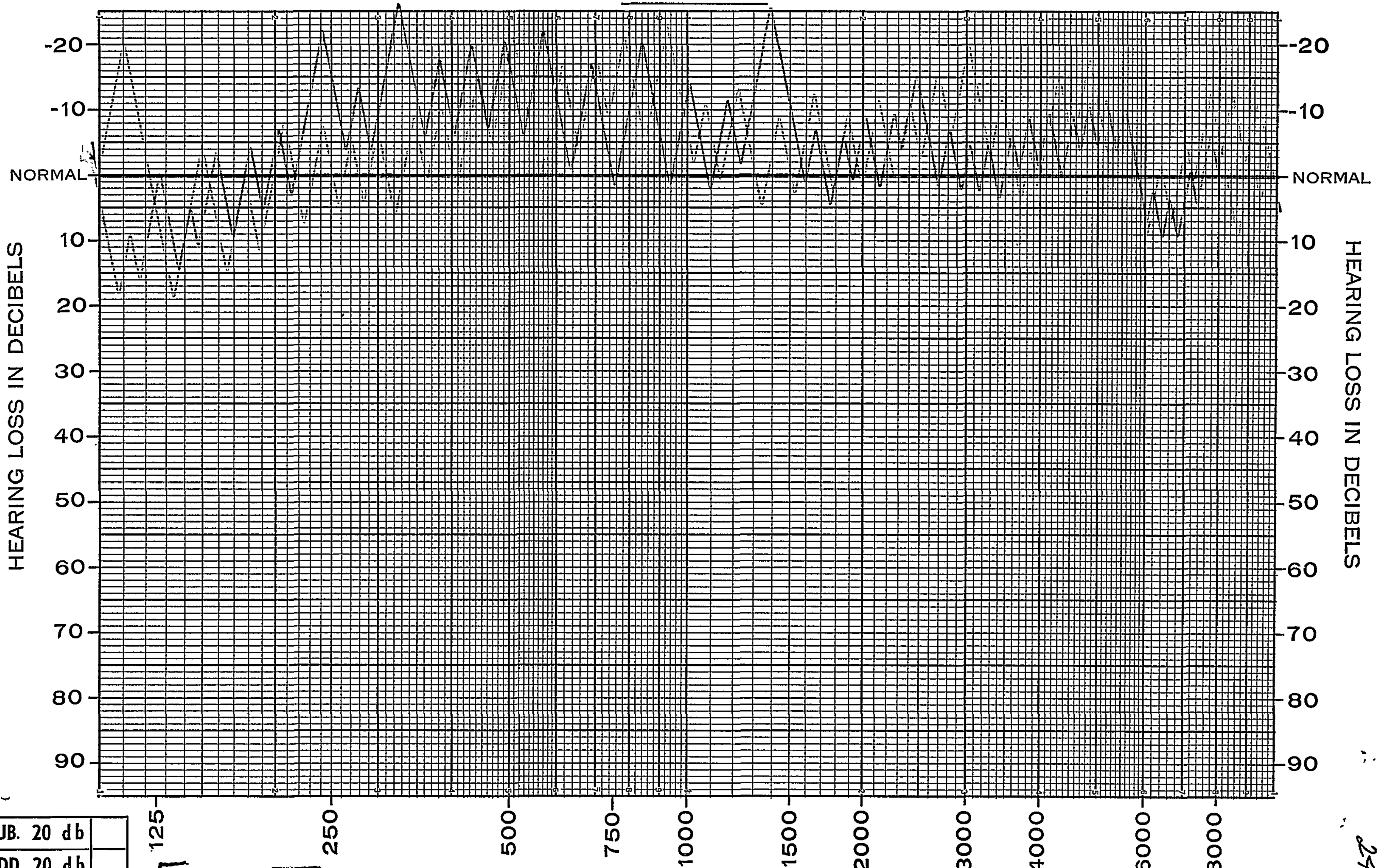
RED: RIGHT MASKING ______ DB.
BLUE: LEFT MASKING ______ DB.

grason stadler

AUDIOGRAM

DATE______ TIME______

BY______




| SUB. 20 db | |
|---|---|
| ADD 20 db | |

Figure II

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TECHNICAL CHARTS INC.

briefly to the good ear. Then the intensity control was changed for the poor ear to an intensity 20 db above the threshold of the poor ear. The tone was briefly presented to the poor ear. The patient indicated whether the first or the second tone was louder. The tone was switched from the good to the poor ear several times, and the intensity of the poor ear was changed as necessary until the patient indicated that the tones were equally loud. The sensation level of the tone in the poor ear was recorded at the point where loudness balance was achieved. This procedure was continued with an increase in the intensity of the tone in the good ear by 10 db. Again the intensity of the tone was varied until the subject indicated that the loudness was balanced. A second note was made of the sensation level of the tone in the poor ear. The procedure was continued in this fashion until the intensity limits of the audiometer had been reached. The same procedure was followed for each of the other frequencies to be balanced.

Reger's Monaural Loudness Balance Test

In the Monaural Loudness Balance Test, the loudness at the impaired frequency was compared with the loudness of the normal frequency. At least a 20 db difference was present between the impaired frequency and the frequency taken as normal. These consisted of either a 1000, 1500, 2000, 3000, 4000, or 6000 cps. tone with no comparisons made with frequencies more than one octave apart.

In administering the test, the following verbal instructions were given:

> "You are going to hear two tones, a first tone and a second tone. Tell me which is louder, the first or second, by saying aloud either 'first' or 'second'."

Assuming that the frequency of 1000 cps. was taken as the standard to which another frequency was to be balanced. The intensity of the 1000 cps. tone was increased by 20 db above threshold and presented briefly. The second and impaired frequency was then given also above threshold. The patient indicated whether the first or second tone was louder. The tone was switched from the standard frequency to the impaired frequency several times until the patient indicated that the tones were equally loud. The sensation level of the standard frequency and the impaired frequency was recorded at the point where loudness balance was achieved. This procedure was continued with an increase in the intensity of the standard frequency by 10 db until the intensity limits of the audiometer were reached.

### Method of Recording Loudness Balance Results

Figure III illustrates the manner of recording the results of the monaural loudness balance test. The points of equal loudness in the good and poor ear were connected by lines under the labeled frequency being balanced. The points on the audiogram for the good ear appear at intervals 10 db apart starting at 20 db above threshold; the points for the poor ear are marked at whatever sensation level was required to balance loudness. If the lines connecting the points of equal loudness remain parallel throughout the course of the test at a specific frequency, no recruitment has been demonstrated since an equal increment of intensity results in an equal increment of loudness in each ear. However, if the lines tended to converge on the poor ear, indicating that increments of loudness in the poor ear were not proportional to the increments of increasing intensity, the presence of recruitment was demonstrated.2/

Figure IV represents the results of the Monaural Loudness Balance Testing. The same method of scoring and delimitation of "No Recruitment," "Incomplete Recruitment," and "Complete Recruitment" was made as in the Binaural Testing. However, the frequencies being balanced are labeled on either side of the designated ear.

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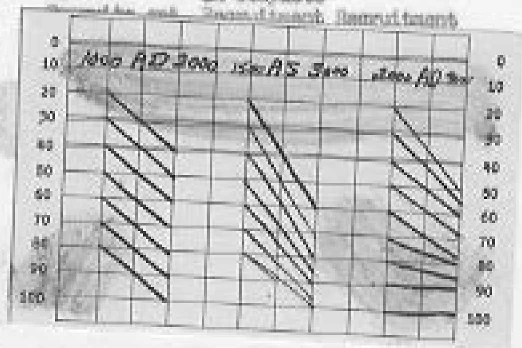
2/Hayes A. Newby, op. cit., p. 169-170.

Figure III

Binaural Loudness Balance T esting

No Recruitment | In complete Recruitment | Recruitment




A d represents the Better Ear; A s represents the Poor Ear

Figure IV

Monaura l Loudness Balance Testing

No Recruitment | Incomplete Recruitment | Recruitment

## Computation of Data

The Loudness Balance Test results were grouped as either Recruitment, Incomplete Recruitment, No Recruitment, Could Not Be Tested, Unreliable, or Not Done. Only those results showing Recruitment and No Recruitment were used in the comparison with the Bekesy data.

The computation of the difference limen from the Bekesy audiogram was determined by averaging the decibel width of all excursions within an octave. The difference limen for recruitment was computed for the octave above the frequency at which recruitment was shown to exist by the loudness balance test. For comparative purposes, the difference limen was computed for the 250 cps. to 500 cps. octave for the same ear on the assumption that recruitment would not exist in that octave.3/

Separate tables were set up for the right and left ear. These tables indicated recruitment with the difference limen results from the fast speed, the frequency 250-500 cps. on the fast speed, slow speed, and the frequency 250-500 cps. on the slow speed. This was also done for the ears showing no recruitment.

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3/As suggested by Dr. Bekesy in an interview.

## Analysis of Data

The difference limen were tabulated in frequency distributions for each of the conditions of recruitment and no recruitment. Chi Square cells were developed to test the significance of any difference that might exist between the recruiting octave and the non-recruiting 250-500 cps. octave.4/

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4/E. F. Lindquist, Educational Measurement, (Wisconsin: George Banta Publishing Company, 1951), p. 289.

## CHAPTER IV

## RESULTS

### Bekesy Test Results - Right Ear

Table II shows the Bekesy Test results for the right ear. The difference limen has been computed for recruitment and no recruitment on the fast speed, 250-500 cps. on the fast speed, slow speed and 250-500 cps. on the slow speed. The results show a scattered frequency distribution for both recruitment and no recruitment. There was no distinct separation between the two groups on the frequency distribution. The mean difference limen was indicated for each criteria and showed a lack of consistency plus no appreciable difference between the recruitment and no recruitment groups.

### Bekesy Test Results - Left Ear

Table III shows the Bekesy Test results for the left ear. The difference limen has been computed for recruitment and no recruitment on the fast speed, 250-500 cps. on the fast speed, slow speed, and 250-500 cps. on the slow speed. The mean difference limen was indicated for each criteria. The results were similar to that of the right ear in that they showed a scattered frequency distribution for both recruitment and no recruitment and that there was no distinct separation between the two groups. The mean difference limen for the left ear also showed a lack of consistency and no appreciable difference between the recruitment and no recruitment groups.

TABLE II

BEKESY TEST RESULTS
RIGHT EAR

| | Recruitment* | | | | No Recruitment** | | | |
|---|---|---|---|---|---|---|---|---|
| DL | Fast Speed | 250-500cps Fast Speed | Slow Speed | 250-500cps Slow Speed | Fast Speed | 250-500cps Fast Speed | Slow Speed | 250-500cps Slow Speed |
| 40 | | | | | | | | |
| 39 | | | | | | | | |
| 38 | | | 1 | | | | | |
| 37 | | | | | | | | |
| 36 | | | | | | | | |
| 35 | 2 | | | | | | | |
| 34 | | 1 | | | | | | |
| 33 | | | | | | | | |
| 32 | 1 | 1 | | | | | | |
| 31 | | | | | | | | |
| 30 | | | | | | | | |
| 29 | | | | | | | | |
| 28 | | 2 | 1 | | | | | |
| 27 | | | | | | | | |
| 26 | | 1 | | | | | | |
| 25 | | 1 | | | | | | |
| 24 | | | | | | | | |
| 23 | | | | | | | 1 | |
| 22 | | | | | | | | |
| 21 | | 1 | | | | | | 1 |
| 20 | | 1 | | 1 | 3 | | | |
| 19 | 1 | | | | | | | |
| 18 | 3 | 2 | | 2 | | | | |
| 17 | 3 | | 1 | 1 | 1 | 2 | | |
| 16 | 2 | 2 | 1 | 1 | | 1 | | |
| 15 | 1 | 2 | 1 | 5 | | | | |
| 14 | 4 | 4 | | 1 | 2 | 1 | | |
| 13 | | 2 | 2 | | | | 2 | 1 |
| 12 | 1 | | 7 | 2 | 1 | 1 | 1 | 1 |
| 11 | | 4 | | 2 | 1 | 2 | | 2 |
| 10 | 3 | 3 | 2 | 2 | 1 | | | 1 |
| 9 | 3 | 1 | 2 | 5 | | 1 | 1 | 1 |
| 8 | 1 | | 2 | 5 | 4 | | 1 | |
| 7 | 2 | | 4 | 1 | | | 1 | |
| 6 | 3 | 2 | 3 | 1 | | | | |
| 5 | | | 1 | 3 | | | | |
| 4 | | | 3 | | | | | 1 |
| 3 | | | 1 | | | | 1 | |
| 2 | | | | | | | | |
| 1 | | | | | | | | |
| Mean D.L. | 14.5 | 15.1 | 10.8 | 11.1 | 11.8 | 13.4 | 10.9 | 11.3 |

| DL | Fast Speed | 250-500cps Fast Speed | Slow Speed | 250-500cps Slow Speed | Fast° Speed | 250-500cps Fast Speed | Slow° Speed | 250-500cps Slow Speed |
|---|---|---|---|---|---|---|---|---|
| 40 | | | | | | | | |
| 39 | | | | | | | | |
| 38 | | 1 | | | | | | |
| 37 | | | | | | | | |
| 36 | | | | | | | | |
| 35 | | | | | | | | |
| 34 | | | | | | | | |
| 33 | | | | | | | | |
| 32 | | | | | | | | |
| 31 | | | | | | | | |
| 30 | 1 | | | | | | | |
| 29 | | | | 2 | | | | |
| 28 | | | | | | | | |
| 27 | 2 | 2 | | | | | | |
| 26 | | | | | | | | |
| 25 | | 1 | | | | | | |
| 24 | | 2 | | | | | | |
| 23 | | | | | | 1 | | |
| 22 | 2 | | 1 | | | | | |
| 21 | 2 | 1 | 1 | 1 | | | | |
| 20 | 1 | 2 | | | 1 | | | |
| 19 | 1 | 1 | 1 | 3 | | | | |
| 18 | 2 | | 1 | 1 | | | | |
| 17 | | 5 | 4 | 1 | | 1 | | |
| 16 | 2 | 2 | 1 | 2 | | | | |
| 15 | 2 | 4 | 1 | 2 | | | | |
| 14 | 2 | 3 | 1 | | | 1 | | 1 |
| 13 | 1 | 4 | 3 | 3 | 3 | 1 | | 1 |
| 12 | 2 | 4 | 2 | 3 | | 2 | | 1 |
| 11 | 4 | 1 | 3 | 4 | 2 | | 1 | |
| 10 | 9 | 5 | 7 | 5 | | | 1 | |
| 9 | 3 | 4 | | 5 | | | 1 | 2 |
| 8 | 2 | 1 | 1 | 9 | 1 | 1 | 2 | 1 |
| 7 | 2 | 1 | 7 | 3 | | 1 | | |
| 6 | | | 5 | 1 | | | | |
| 5 | 3 | | 5 | | 1 | | 2 | 1 |
| 4 | 1 | | | | | | | |
| 3 | | | 1 | | | | | |
| 2 | | | | | | | | |
| 1 | | | | | | | | |
| Mean D.L. | 13.2 | 15.3 | 10.5 | 12.4 | 11.8 | 13.3 | 8 | 10 |

* Data applying to recruiting ears.

** Data applying to non-recruiting ears.

*** Frequency distribution of difference limen for the octave above the frequency at which the loudness balance test was conducted.

**** Frequency distribution for the non-recruiting octave.

° Difference limen for the octave above the frequency at which the loudness balance test was conducted but at which no recruitment was indicated.

TABLE IV

CHI SQUARE VALUES

Table IV shows Chi Square values on the right and left ears for the recruitment octave versus the 250-500 cps. octave on the fast and slow speed. In order to be significant at the 0.5 level of confidence a Chi Square must be at least 1.90. This was not indicated in any of the Chi Square values done. No computation was done for the ears showing no recruitment as the group was too small.

TABLE IV

CHI SQUARE VALUES

| | |
|---|---|
| Recruitment octave vs. 250-500cps. octave-Fast Speed-Rt. Ear | 0 |
| Recruitment octave vs. 250-500cps. octave-Slow Speed-Rt. Ear | 0 |
| Recruitment octave vs. 250-500cps. octave-Fast Speed-Lt. Ear | 1.7 |
| Recruitment octave vs. 250-500cps. octave-Slow Speed-Lt. Ear | .21 |

## CHAPTER V

## SUMMARY AND CONCLUSIONS

### Summary

This investigation compared the Bekesy-type Test with Fowler's Binaural and Reger's Monaural Loudness Balance Test for recruitment. The specific objective was to determine whether the difference limen as measured by the Bekesy-type audiometer can discriminate between recruiting and non-recruiting ears as shown by the loudness balance method. One hundred and sixty-seven subjects between the ages of 50 and 90 were available for the study.

The audiological assessment included Bekesy testing at fast and slow speeds and Loudness Balance Testing when possible. The loudness balance test results were divided into groups showing Recruitment, Incomplete Recruitment, Could Not Be Tested, Unreliable, or Not Done. Only those results showing Recruitment and No Recruitment were used in the comparison with the Bekesy data. The Bekesy results were computed into difference limen by averaging the width of all excursions within an octave. The difference limen for recruitment and no recruitment was computed for the octave above the frequency at which recruitment and no recruitment was shown to exist by the loudness balance test. For comparative purposes, the difference limen was computed for the 250-500 cps. octave on the assumption that recruitment would not exist in that octave. Frequency distributions for the difference limen were scattered and there was no distinct separation between the two groups. The mean difference limen for each ear showed lack of consistency and no appreciable difference between the recruiting and non-recruiting groups. Chi Square values showed no significant difference between the right and left ears for the recruitment octave versus the 250-500 cps. octave on the fast and slow speed.

## Conclusions

This investigation indicates that the Bekesy-type audiometer cannot discriminate between recruiting and non-recruiting ears as shown by the loudness balance method.

## Limitations

1. More control would have been possible if the data used had been collected for this specific study instead of being gathered for the general hearing evaluation in the Hearing and Communication Project.

2. One tester instead of two would have eliminated any possible difference in technique.

3. The data did not include comparison groups of those known to have normal hearing.

4. Loudness Balance Testing was done on only one possible area.

5. The group studied showed an erratic response to the Bekesy Testing.

Suggestions for Further Research

1. A comparison of the difference limen results from Bekesy-type Testing with loudness balance test results in subjects with Meniere's Disease.

2. An investigation of different methods to determine the difference limen measurement on the Bekesy audiogram.

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# APPENDIX A

| Subj.# | Loudness Balance Test | | Bekesy | Fast Speed | | | | Slow Speed | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 250-500 Cps | | | | 250-500 Cps | |
| | Frequency Tested in Cps | Result | Frequency Tested in Cps | #Peaks | DL | #Peaks | DL | #Peaks | DL | #Peaks | DL |
| 773 | 1000 + 1500 | R | 2000 - 4000 | 8 | 16 | 5 | 28 | --- | -- | --- | -- |
| 665 | 1000 + 1500 | R | 2000 - 4000 | 10 | 14 | 11 | 14 | 10 | 7 | 15 | 9 |
| 191 | 1000 + 1500 | R | 1000 - 2000 | 4 | 35 | 6 | 26 | 11 | 12 | 9 | 15 |
| 661 | 1000 + 2000 | R | 2000 - 4000 | 7 | 19 | 7 | 20 | 13 | 10 | 8 | 18 |
| 369 | 1000 + 2000 | R | 2000 - 4000 | -- | -- | -- | -- | 34 | 4 | 16 | 8 |
| 315 | 1000 + 2000 | R | 2000 - 4000 | 11 | 14 | 5 | 28 | 10 | 7 | 11 | 12 |
| 212 | 1000 + 2000 | R | 1000 - 2000 | 13 | 9 | 10 | 14 | -- | -- | -- | -- |
| 824 | 1500 + 2000 | R | 2000 - 4000 | 15 | 8 | 12 | 11 | 16 | 7 | 13 | 10 |
| 709 | 1500 + 2000 | R | 2000 - 4000 | 12 | 10 | 9 | 16 | 21 | 6 | 17 | 8 |
| 358 | 1500 + 3000 | R | 2000 - 4000 | 20 | 6 | 15 | 9 | 14 | 9 | 8 | 18 |
| 780 | 2000 + 3000 | R | 3000 - 6000 | 7 | 17 | 5 | 25 | 12 | 10 | 11 | 12 |
| 749 | 2000 + 3000 | R | 3000 - 6000 | 8 | 16 | 14 | 10 | 11 | 12 | 19 | 6 |
| 453 | 2000 + 3000 | R | 3000 - 6000 | 4 | 32 | 7 | 21 | -- | -- | -- | -- |
| 368 | 2000 + 3000 | R | 3000 - 6000 | 9 | 16 | 8 | 18 | 6 | 38 | 17 | 8 |
| 299 | 2000 + 3000 | R | 4000 - 8000 | 4 | 35 | 4 | 34 | 10 | 15 | 9 | 16 |
| 243 | 2000 + 3000 | R | 3000 - 6000 | 13 | 14 | 7 | 16 | 16 | 9 | 15 | 9 |
| 270 | 2000 + 3000 | R | 4000 - 8000 | 10 | 14 | 10 | 14 | 9 | 16 | 9 | 15 |
| 224 | 2000 + 3000 | R | 3000 - 6000 | -- | -- | -- | -- | 11 | 12 | 9 | 15 |
| 281 | 2000 + 4000 | R | 2000 - 4000 | 8 | 15 | 8 | 18 | 12 | 12 | 13 | 11 |
| 222 | 2000 + 4000 | R | 4000 - 8000 | -- | -- | -- | -- | 10 | 13 | 13 | 9 |
| 648 | 3000 + 4000 | R | 1500 - 3000 | 13 | 10 | 9 | 15 | 16 | 8 | 12 | 10 |
| 528 | 3000 + 4000 | R | 2000 - 4000 | 20 | 6 | 13 | 10 | 22 | 6 | 23 | 5 |
| 237 | 3000 + 4000 | R | 3000 - 6000 | -- | -- | -- | -- | 5 | 28 | 9 | 17 |
| 213 | 3000 + 4000 | R | 3000 - 6000 | 17 | 7 | 13 | 11 | 21 | 6 | 14 | 5 |
| 669 | 4000 + 6000 | R | 2000 - 4000 | -- | -- | -- | -- | 12 | 12 | 9 | 15 |
| 764 | 4000 + 6000 | R | 2000 - 4000 | 14 | 10 | 10 | 14 | 19 | 7 | 14 | 9 |
| 662 | 1000 | R | 1500 - 3000 | 11 | 12 | 13 | 10 | 26 | 4 | 15 | 8 |
| 558 | 1000 | R | 1500 - 3000 | 24 | 7 | 22 | 6 | 27 | 4 | 22 | 5 |
| 752 | 2000 | R | 2000 - 4000 | 16 | 9 | 12 | 11 | 33 | 3 | 17 | 8 |
| 704 | 3000 | R | 1500 - 3000 | 7 | 17 | 5 | 32 | 8 | 17 | 7 | 20 |
| 637 | 3000 | R | 1500 - 3000 | 19 | 9 | 11 | 11 | 15 | 8 | 13 | 10 |
| 661 | 4000 | R | 2000 - 4000 | 20 | 6 | 22 | 6 | 24 | 5 | 18 | 7 |
| 746 | 6000 | R | 3000 - 6000 | 8 | 18 | 10 | 13 | 12 | 13 | 12 | 11 |
| 730 | 6000 | R | 3000 - 6000 | 8 | 17 | 9 | 15 | 11 | 12 | 9 | 15 |
| 805 | 8000 | R | 3000 - 6000 | 8 | 18 | 10 | 13 | 11 | 12 | 10 | 14 |
| 654 | 1500 + 3000 | NR | 3000 - 6000 | 7 | 20 | 8 | 17 | 11 | 13 | 14 | 9 |
| 667 | 1500 + 3000 | NR | 2000 - 4000 | 12 | 11 | 8 | 17 | 11 | 12 | 11 | 12 |
| 230 | 2000 + 3000 | NR | 3000 - 6000 | 9 | 14 | 9 | 16 | 6 | 23 | 6 | 21 |
| 687 | 2000 + 3000 | NR | 2000 - 4000 | 16 | 8 | 14 | 9 | 31 | 3 | 27 | 4 |
| 761 | 2000 + 3000 | NR | 3000 - 6000 | 9 | 14 | 11 | 11 | 16 | 8 | 11 | 11 |
| 364 | 2000 + 4000 | NR | 4000 - 8000 | 8 | 17 | 12 | 11 | 13 | 9 | 14 | 10 |
| 685 | 2000 + 4000 | NR | 1500 - 3000 | 13 | 10 | 10 | 14 | 18 | 7 | 11 | 12 |
| 233 | 3000 | NR | 2000 - 4000 | 11 | 12 | 11 | 12 | 11 | 13 | 13 | 11 |

# APPENDIX B

# Tabulations for Left Ear

| Subj.# | Loudness Balance Test | | Bekesy | Fast Speed | | | | Slow Speed | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 250-500 Cps | | | | 250-500 Cps | |
| | Frequency Tested in Cps | Result | Frequency Tested in Cps | #Peaks | DL | #Peaks | DL | #Peaks | DL | #Peaks | DL |
| 773 | 1000 + 1500 | R | 2000 - 4000 | 12 | 11 | 8 | 17 | 9 | 17 | 5 | 29 |
| 665 | 1000 + 1500 | R | 2000 - 4000 | 10 | 14 | 9 | 14 | 13 | 10 | 14 | 10 |
| 685 | 1000 + 1500 | R | 2000 - 4000 | 13 | 10 | 11 | 12 | 11 | 12 | 17 | 8 |
| 544 | 1000 + 2000 | R | 1000 - 2000 | 12 | 12 | 13 | 10 | 20 | 6 | 15 | 9 |
| 480 | 1000 + 2000 | R | 2000 - 4000 | 19 | 8 | 16 | 9 | 21 | 6 | 14 | 9 |
| 369 | 1000 + 2000 | R | 2000 - 4000 | 33 | 4 | 16 | 8 | -- | -- | -- | -- |
| 315 | 1000 + 2000 | R | 2000 - 4000 | 15 | 8 | 8 | 17 | 19 | 7 | 14 | 9 |
| 486 | 1000 + 4000 | R | 2000 - 4000 | 24 | 5 | 14 | 9 | 24 | 5 | 17 | 8 |
| 700 | 1500 + 3000 | R | 1500 - 3000 | -- | -- | -- | -- | 8 | 17 | 5 | 29 |
| 385 | 1500 + 3000 | R | 4000 - 8000 | 7 | 21 | 6 | 25 | 12 | 13 | 12 | 11 |
| 654 | 1500 + 3000 | R | 2000 - 4000 | 9 | 16 | 9 | 15 | 13 | 10 | 15 | 10 |
| 806 | 1500 + 3000 | R | 2000 - 4000 | 5 | 27 | 7 | 9 | 9 | 16 | 9 | 17 |
| 780 | 2000 + 3000 | R | 2000 - 4000 | 7 | 21 | 7 | 19 | 14 | 10 | 11 | 13 |
| 749 | 2000 + 3000 | R | 4000 - 8000 | 17 | 10 | 11 | 13 | 12 | 11 | 17 | 8 |
| 738 | 2000 + 3000 | R | 4000 - 8000 | 15 | 9 | 12 | 11 | 20 | 6 | 17 | 8 |
| 314 | 2000 + 3000 | R | 3000 - 6000 | 7 | 22 | 5 | 27 | 8 | 18 | 9 | 15 |
| 355 | 2000 + 3000 | R | 1500 - 3000 | 5 | 30 | 7 | 20 | 8 | 17 | 9 | 16 |
| 395 | 2000 + 3000 | R | 4000 - 8000 | 13 | 10 | 14 | 10 | 16 | 7 | 18 | 7 |
| 482 | 2000 + 3000 | R | 1500 - 3000 | 10 | 13 | 11 | 13 | 11 | 14 | 12 | 12 |
| 572 | 2000 + 3000 | R | 4000 - 8000 | 8 | 18 | 4 | 38 | 9 | 17 | 8 | 19 |
| 712 | 2000 + 3000 | R | 2000 - 4000 | -- | -- | -- | -- | 11 | 13 | 7 | 19 |
| 255 | 2000 + 3000 | R | 3000 - 6000 | 10 | 15 | 10 | 14 | 9 | 15 | 13 | 10 |
| 701 | 2000 + 3000 | R | 2000 - 4000 | -- | -- | -- | -- | 12 | 10 | 15 | 9 |
| 693 | 2000 + 3000 | R | 3000 - 6000 | 14 | 9 | 9 | 17 | 19 | 5 | 16 | 8 |
| 624 | 2000 + 4000 | R | 1500 - 3000 | 26 | 5 | 14 | 10 | 23 | 5 | 14 | 10 |
| 243 | 2000 + 4000 | R | 3000 - 6000 | 13 | 11 | 9 | 15 | 19 | 7 | 17 | 8 |
| 222 | 2000 + 4000 | R | 3000 - 6000 | -- | -- | -- | -- | 17 | 7 | 17 | 8 |
| 370 | 2000 + 4000 | R | 4000 - 8000 | -- | -- | -- | -- | 24 | 5 | 14 | 9 |
| 528 | 3000 + 4000 | R | 2000 - 4000 | 14 | 9 | 13 | 10 | 16 | 7 | 16 | 8 |
| 669 | 4000 + 6000 | R | 2000 - 4000 | -- | -- | -- | -- | 11 | 12 | 9 | 15 |
| 261 | 4000 + 6000 | R | 2000 - 4000 | 13 | 10 | 11 | 12 | 18 | 7 | 12 | 12 |
| 202 | 1000 | R | 1500 - 3000 | 18 | 7 | 14 | 10 | 21 | 6 | 19 | 7 |
| 358 | 1500 | R | 3000 - 6000 | 19 | 7 | 19 | 7 | 34 | 3 | 18 | 7 |
| 453 | 1500 | R | 1500 - 3000 | 7 | 22 | 6 | 24 | -- | -- | -- | -- |
| 788 | 1500 | R | 1500 - 3000 | 11 | 12 | 11 | 13 | 17 | 7 | 12 | 11 |
| 422 | 1500 | R | 1500 - 3000 | 13 | 10 | 14 | 9 | 12 | 10 | 21 | 6 |
| 550 | 1500 | R | 3000 - 6000 | -- | -- | -- | -- | 13 | 11 | 10 | 13 |
| 256 | 2000 | R | 3000 - 6000 | 12 | 10 | 5 | 24 | -- | -- | -- | -- |
| 201 | 2000 | R | 3000 - 6000 | 12 | 10 | 8 | 16 | -- | -- | -- | -- |
| 235 | 2000 | R | 3000 - 6000 | 13 | 10 | 11 | 12 | -- | -- | -- | -- |
| 118 | 2000 | R | 2000 - 4000 | 9 | 14 | 9 | 15 | 15 | 8 | 10 | 13 |
| 623 | 2000 | R | 2000 - 4000 | 26 | 5 | 11 | 12 | 21 | 6 | 15 | 8 |
| 452 | 3000 | R | 1500 - 3000 | 5 | 27 | 5 | 27 | 6 | 21 | 8 | 19 |
| 555 | 3000 | R | 3000 - 6000 | 9 | 16 | 9 | 15 | 26 | 5 | 13 | 10 |
| 799 | 3000 | R | 4000 - 8000 | 12 | 11 | 8 | 17 | 10 | 13 | 9 | 16 |
| 106 | 4000 | R | 4000 - 8000 | 8 | 18 | 6 | 21 | 13 | 10 | 7 | 18 |
| 399 | 4000 | R | 1500 - 3000 | 12 | 11 | 11 | 13 | 12 | 11 | 12 | 11 |
| 503 | 4000 | R | 4000 - 8000 | 7 | 20 | 7 | 20 | 7 | 22 | 12 | 11 |
| 511 | 4000 | R | 1500 - 3000 | 9 | 15 | 8 | 17 | -- | -- | -- | -- |
| 716 | 4000 | R | 3000 - 6000 | 13 | 10 | 10 | 14 | 8 | 19 | 6 | 21 |
| 751 | 6000 | R | 2000 - 4000 | 7 | 19 | 8 | 16 | 13 | 10 | 11 | 12 |
| 230 | 2000 + 3000 | NR | 3000 - 6000 | 11 | 13 | 10 | 13 | -- | -- | -- | -- |
| 687 | 2000 + 3000 | NR | 3000 - 6000 | 15 | 8 | 14 | 9 | 22 | 10 | 9 | 14 |
| 761 | 2000 + 3000 | NR | 3000 - 6000 | 10 | 13 | 11 | 12 | 15 | 8 | 14 | 9 |
| 161 | 2000 + 3000 | NR | 1500 - 3000 | 11 | 11 | 10 | 14 | 25 | 5 | 17 | 8 |
| 291 | 2000 + 4000 | NR | 1000 - 2000 | 11 | 13 | 9 | 17 | 12 | 11 | 11 | 12 |
| 295 | 2000 + 4000 | NR | 1500 - 3000 | 12 | 11 | 11 | 12 | 15 | 8 | 14 | 9 |
| 411 | 1500 | NR | 3000 - 6000 | 26 | 5 | 21 | 6 | 21 | 5 | 23 | 5 |
| 378 | 6000 | NR | 2000 - 4000 | 7 | 20 | 6 | 23 | 14 | 9 | 10 | 13 |