OBJECTIVE RESIDUAL MONAURAL LOUDNESS ADAPTATION - A NEW CONCEPT

A Thesis Submitted To The University of Mysore For The Degree of
DOCTOR OF PHILOSOPHY

M. N. VYASA MURTHY, M.SC,

AN India Institute of Speech And Hearing
Mysore-570 006, INDIA

May 1982

TO
MY STUDENTS (SUBJECTS).

WHOM I HAVE

TORTURED

DECLARATION

I declare that this thesis entitled, OBJECTIVE RESIDUAL MONAURAL LOUDNESS ADAPTATION -- A NEW CONCEPT, which is submitted here with for the award of the degree of Doctor Of Philosophy of the University of Mysore is the result of the work carried out by me at the All india Institiute of speech and Hearing, Mysore 6, under the guidance of Dr. Vijay A. Shah, Head, Deptt. of Audiology, H.N Hospital, Bombay, and Consultant J.J. Hospital, Bombay.

I further declare that the results of this work have not been previously submitted for any degree or fellowship.

M.N. VYASAMURTHY
8/4/82

CERTIFICATE

this is to certify that the thesis entitled OBJECTIVE RESIDUAL MONAURAL LOUDNESS ADAPTATION A NEW CONCRCPY submitted by Mr. M.N. Vyasa Murthy for the degree of Doctor of Philosophy of the University of Mysore is the result of research work done by him at the All india Institute of Speech and Hearing Mysore 570 006, under my guidance.

Vijay A Shah
DR.VIJAY A. SHAH
GUIDE

Head
Deptt.,of Audiology
H.N. Hospital
Bombay and
consultant, J.J, Hospital
Bombay

Date: 8th April 1982

ACKNOWLEDGEMENT

I wish to acknowledge my profound lndebtedness to Dr. Vijay A. Shah, Head, Daptt. of Audiology, H.N Hospital. Bombay and Consultant, J.J. Hospital, Bombay without whose invaluabla guidance, constant interest & unceasing lnspiration, the thesis in Its present form could not have been achived.

I am highly grateful to Dr. Arnold, M. Small, Visitng Scholar, Hearing and Speech Sciences,Divison of Otolaryagology, Stanford University Medical Center, Stanford, California, 94305 (USA), for him useful comments on my paper entitled, "Objective Verification of Small's Model for Loudness Adaptation" which was sent to him during December, 1976. Also, I am very thankful for his encouragementnt.

My thanks are due to Dr. N. Rathna, Director,AIISH, Mysore 6, and Dr. S. Nikam, Professor and Head, Deptt. of Audiology, AIISH, Mysore 6, for their permission to carry out the investigation at AIISH, Mysore - 6. Also, I express my gratitude for their encouragement.

My thanks are also due to Mr.S.S Murthy, Lecturer in Electronics, Mr. Narayana Raju, Electronics Engineer and Miss Jayashree, for their help.

I am highly thankful to Shri T. Keshava Murthy, senior Stenographer. AIISH,Mysore 6. for his excellent work.

I am thankful to each and everyone who is directly or indirectly responsiblel for the present study.

LIST OF TABLES

List of Tables continued

List of Tables continued

Table Page

CONTENTS

SYNOPSIS **Page**

SYNOPSIS

OBJECTIVE RESIDUAL MONAURAL LOUDNESS ADAPTATION - A NEW CONCEPT

Many investigators have presented evidences for both qualitative and quantitative similarities between acoustic reflex and the perception of loudness. There are experimental evidences to show that signals at the threshold of acoustic reflex may be equally loud for listeners with normal hearing. A relation between loudness and acoustic reflex response exists if signals especially 0.5 KHz and 1 KHz are equated in terms of the magnitude of the middle ear muscle response. In the light of the evidences provided by many investigators including the author, it may not be unreasonable to assume that there is a relationship between loudness and acoustic reflex response in normal hearing subjects, under the established conditions.

Additionally, we have Borg and Odman's confirmation that decay and recovery originate in the afferent auditory systems and not in the acoustic reflex muscles. Reflex decay (or reflex adaptation) studies reported in the literature are quite different from the present study as the

---

*See Gorga, M,P.; Lilly, D.J., and Length, R.V., - Effect of signal band width upon threshold of the acoustic reflex and upon loudness. Audlology 19: 277 - 292 (1980).

former studies are concerned with concomitant adaptation, whereas the latter one is concerned with residual adaptation.

Many controversies are prevailing as far as loudness coding during auditory adaptation is concerned, Studies relating to the amount of adaptation as a function of intensity, duration and frequency of the stimulus are in conflict. Recently, Weiler and his co-investigators have reported significant positive adaptation using a monaural technique viz., Monaural Hetereophonic (MH). This is in contrast to the recent reports by many researchers who have observed no adaptation when the test conditions were designed to eliminate lateralising effects and binaural interaction between adapting and comparison tones. Till date, no clear reasons could be given for the differences observed among the different methods.

A new objective technique viz., ORMLA(Objective Residual Monaural loudness Adaptation) was developed for measuring adaptation. This technique satisfies most of the criteria prescribed by Small for the measurement of'adequate'adaptation.

The thesis* deals with adaptation measurements made

---

*Portions of this study were presented at the IX Annual conference of Indian Speech and Hearing Association held at Bangalore during Jan.. 1977 under the title:'Objective Verification of Small's model of loudness Adaptation', (This paper got Dr.Desa's Best Paper Award).

using the new technique. The resulting data led the investigator to develop a revised model for loudness coding during auditory adaptation. The revised model provides answers to many of the controversies prevailing in the area of auditory adaptation - and also the revised model appears to be a 'break-through' in auditory physiology.

The subjects participating in the different experiments consisted of 32 to 48 normally hearing (20 dB HI,, ANSI 1969) students of at the All India Institute of Speech and Hearing, Mysore 570 006,India, ranging in age from 19 to 27 years. The adapting stimulus was always presented to the left ear and monitoring of the reflex response was done in the right ear (air-pressure in the right ear canal was set at 0 mm H 2 o). The changes in the magnitude of reflex response (stiffness changes of the middle-ear system) as indicated by the deflection of the Balance Meter (BM) needle of a calibrated electro-acoustic impedance bridge - Madsen ZO 73 were noted down at different intensities of the test tone before adapting the ear. Consistent 'BM readings' at different intensity levels of the test tone were noted. The inter-stimulus interval was 30 sec for test tones < 100 dB SPL and 60 sec for test tones 100 dB SPL. The duration of each presentation of the test tone was 1.5 sec.

After noting down the 'BM readings' for the test tone at different intensity levels, the probe tone (220 Hz)in

The procedure for finding recovery time from adaptation was exactly same as the procedure used for measuring adaptation, but with a little difference. The measurement of adaptation did not stop at single presentation of the test tone(for 1.5 sec) 5 sec after the withdrawal of the adapting stimulus. The test tone was repeatedly presented once in 60 sec for 1.5 sec and each time 'BM reading' was noted. This procedure was continued until the magnitude of reflex('BM reading')was the same as the 'BM reading' produced by the test tone during preadapted condition (in experiments IXb and IXc recovery process was studied for 10 min, of post adapted condition). The 'BM reading' obtained at 60 sec intervals were compared with the 'BM readings' which were recorded during pre-adapted condition to compute adaptation (in dB) at 60 sec intervals of recovery time.

The results of the experiments can be summarized as follows:

Experiment - I

To know whether pure tones of frequencies viz., 0.5 KHz, 1 KHz and 2 KHz at equal loudness levels would produce equal magnitude of reflex in normal hearing subjects, 8 subjects (5M + 3F) in the age range 20 to 25 Yrs were tested. The results showed that in all the 8 subjects the magnitude of reflex as indicated by the BM needle deflection for 0.5 KHz and 1 EEz tones at 120 dB SPL was the probe ear (Right Ear) was put off. Then, the adapting stimulus was presented continuously (duration, intensity and frequency of the adapting stimulus varied depending on the type of experiment). At the end of the required duration of exposure of the adapting stimulus, the adapting stimulus was withdrawn and after 5-sec. rest period, (this rest period was required for setting the knobs) the test tone at a level depending on the type of experiment was presented for 1.5 sec. The 'BM reading' was noted. This reading was compared with the 'BM readings' of the pre-adapted test tone levels. The pre-adapted test tone level, which had produced the same 'BM reading' (magnitude of reflex) as that of the post adapted test tone, was identified. Adaptation (in dB) was the difference between the post-adapted test tone level and the pre-adapted test tone level which produced the same 'BM reading' (magnitude of reflex) as that of the post adapted test tone. This way, loudness adaptation was measured in decibels (dB) objectively. loudness adaptation measured in the above manner has been termed 'objective Residual Monaural Loudness Adaptation' (ORMLA).

'BM readings' for pre-adapted test tone levels were recorded prior to <u>each</u> adaptation test. A minimum of 24 to 48 hrs rest, between adaptation tests, was allowed for each subject to ensure complete recovery from the fatigue processes.

exactly the same; however, for 2 KHz tone the magnitude of reflex at 120 dB SPL was less than the magnitude of reflex observed at 0.5 KHz and 1 KHz. Further, it was also observed that the magnitude of reflex increased with the increase in intensity above 120 dB SPL and decreased with the decrease in the intensity below 120 dB SPL. The magnitude of reflex was not the same for 0,5 KHz, 1 KHz and 2 KHz at 100 dB SPL. This is quite expected, as we know through equal loudness contours that at 100 dB SPL, the above tones are not heard equally loud. This result showed that for pure tones viz., 0.5 KHz and 1 KHz, the magnitude of reflex is a measure of loudness perceived by the subjects.

The above findings and the findings of other investigators. were used as the basis for the experiments reported here.

Experiment II

A control study, was carried out to ensure that the magnitude of reflex observed at different intensity levels remained the same after 7-min. of silent interval. This study was done on 8 subjects ranging in age from 20 to 22 Yrs. There was no significant difference at 0.01 level between the two readings at all the intensity levels tested. There were some subjects who did not show consistent magnitude of reflex and those subjects were not included in the study. The subjects who showed consistent magnitude of reflex at a constant level of the test tone and consistent increase in the magnitude of reflex with the increase in the intensity of the test tone were selected for all the experiments of the present study.

Experiment III

(a) 34 subjects (16M + 18F) ranging in age from 19 to 26 Yrs (Mean age = 20.9) showed the mean adaptation (dB) values of 5.22, 7.98, 10.59 and 9.56 to 2 KHz adapting tone at 110 dB SPL, for exposure duration of 3,5, 7 and 9 min. respectively. Asymptbtic state reached by 7-min. in all the subjects.

(b) The mean (6 trials on the same subject - the investigator) adaptation values for 0.5 KHz, 1 KHz and 2 KHz at 110 dB SPL, adapted for 3,5,7 and 9-min. were : 4.58, 5.83, 9.16 and 9.58; 6,66, 9.58, 9.16 and 10.0; 5.83, 7.92, 14.76 and 14.58 respectively.

Experiment IV

(a) 31 subjects (12M + 19F) ranging in age from 19 to 25 Yrs. (Mean age = 20.3) showed mean adaptation values of 11.61 (3D = 5.45) and 19.42 (S.D =6.13) for adapting frequencies viz;* 0.5 KHz and 1 KHz at 125 dB SPL for 3-min. continuous exposure, respectively. The results showed significant difference between the two means.

(b) Mean adaptation values obtained for 33 subjects (16M + 17F) in the age range 19 to 27 yrs. (Mean age = 20.75) for 1 KHz and 2 KHz adapting tones, adapted for 7-min. at 110 dB SPL were 7.65 (S.D=3.34) and 11.44 (S.D = 3.67) respectively. The results showed significant difference between the two means,

(c) Mean adaptation values (6 trials on the same subject - the investigator) for the adapting frequencies 0.5 KHz and 1 KHz at 125 dB SPL (i.e., at equal magnitude of reflex-implying that the adapting tones were presented at equal loudness levels for 7-min., were 20.83 (S.D = 1.18) and 22.20 (S.D = 195) respectively. The results showed, that the 'frequency effect' was negligible when the adapting tones at different frequencies were presented at equal loudness levels for 7-min.

Experiment V

(a) 1 KHz at 110 dB SPL for 3-min. was used as the adapting stimulus. Adaptation was measured separately at test tones 1 KHz and 2 KHz (110 dB SPL). The mean adaptation values obtained were:4.85 (S.D=3.25) at 1 KHz and 2.94 (S.D=3.16) at 2 KHz. 34 subjects (19M + 15F) in the age range of 19 to 25 yrs. were used in this experiment.

(b) 1 KHz at 125 dB SPL for 7-min, was used as the adapting stimulus. Adaptation was measured separately at test tones 0.5 Hz, 1 KHz and 2 KHz (Adaptation was measured at 125 dB SPL for all the test tones). Mean adaptation values (6 trials on the same subject - the investigator) at 1 KHz,0.5KHz and 2 KHz were: 20.53 (S.D = 1.18), 14.58 (SD=0.93) and 19.60 (S.D = 1.71) respectively.

The above experiments showed that adaptation was maximum at the adapting frequency and that there was spread of adaptation to neighbouring frequencies. These findings could be viewed as not out of line with the data reported by other investigators.

Experiment VI

(a) Mean adaptation values (base-line condition)for 1 KHz presented continuously for 3-min at intensities viz.,100 dB SPL, 110 dB SPL and 120 dB SPL were: 1.91 (S.D = 2.23), 8.89 (S.D = 3.89) and 18.16(S.D = 4.81) respectively. 34 subjects (M=13, F=21) in the age range 19 to 26 Yrs. (Mean age = 21.6) were tested. Friedman test indicated that – the over-all increase between 100 dB SPL and 120 dB SPL was significant. (X2 = 63.18; d.f = 2, P 0.001). The increase between 100 dB SPL, and 110 dB SPL, was significant (X2 = 24.7; df = 1, P 0,001).

The increase between 110 dB SPL and 120 dB SPL was significant (X2 = 33.9; df = 1, P 0.001).

(b) Mean adaptation values obtained for 10 adult subjects (6F + 4M) for adapting stimulus of 1 KHz tone adapted for 7-min. at 105, 115 and 125 dB SPL were: 4.5 (S.D = 1.5), 9.5 (S.D = 3.5) and 22.0 (S.D = 7.61) respectively.

The above experiments showed that (Xb) adaptation measured at the intensity of the adapting stimulus (base-line condition) was linear with the intensity of the adapting stimulus. These results are in contrast to the results obtained by SDLB method.

Experiment VII

(a) Mean adaptation values, obtained at 100 dB SPL (1 KHz) when the ear was adapted using 1 KHz tone at two different intensities viz., 105 and 115 dB SPL, separately, for 7-min, were: 4.84 (S.D = 3.55) and 5.08 (S.D = 3.56) respectively. The differences were not significant (X2 = 0.5; df = 1, P> 0.5). 32 subjects (18F + 14M) in the age range 19 to 26 Yrs. (Mean age = 20.4) participated in this experiment. The results showed that adaptation depends on the intensity at which it was measured, but not on the intensity at which the ear was adapted ; thus the present results could be viewed as not out of line with past findings,

(b) Experiment similar to VII (a) was carried out at very high intensity levels using 7 adult subjects (4F + 3M) . Adaptation (X_L) was measured at 105 dB SPL after the ear was adapted to 1 KHz for 4-min at 125 dB SPL and 115 d3 separately. Mean adaptation values were: 17.85 (S.D=4.51) and 17.85 (S.D=4.51) for adapting intensities of 125 dB SPL and 115 dB SPL respectively.

The results obtained in VII (a) and VII (b) confirm Small's prediction.

(c) To know whether X, (adaptation measured at an intensity less than the adapting intensity)was less than X_b (adaptation measured at the adapting intensity or also called adaptation at the base-line condition), X_L was measured at 100 dB SPL and X_b was measured at 110 dB SPL - 1 KHz tone at 110 dB SPL for 7-min. was used as the adapting stimulus. 38 subjects (21 M + 17F) in the age range 19 to 24 Yrs. (Mean age = 20.3) participated in this experiment. Mean X_b was 7.96 (S.D = 3.38) and Mean X_L was

4.28 (S.D. = 3.08), Friedman test showed that the differences in the amounts of adaptation were significant, ($x2$ = 26.95; df = 1; P 0.001).

Experiment VIII

(a) 43 subjects (19M + 24F) In the age range 19 to 25 Irs (Mean age = 20.8) showed Mean X_b and Mean X_h (adaptation measured at an intensity higher than the adapting intensity) values of 6.39 (S.D = 3.86) and 8.78 (S.D. = 4.77) respectively. 1 KHz at 110 dB SPL for 7-min, was used as the adapting stimulus. X_h was measured at 120 dB SPL. Significant differences were observed between the two conditions ($x2 = 8,29$; df = 1; $p < 0.001$).13 showed : $X_h = X_b > 0$,

4 subjects showed : $X_h < X_b > 0$,& 7 subject s showed $X_h > X_b$ 0

(b) 5 adult subjects (3F + 2M) were tested for X_h and X_b values using very high adapting intensity. X_b was obtained for 1 KHz tone at 125 dB SPL for 4-min. adaptation. Xh was obtained at 135 dB SPL. Mean values of X_h and X_b were: 4.0 (S.D = 4.89) and 13.0 (S.D = 4.0) respectively. This experiment showed that $X_h < X_b > 0$ resulted when the adapting intensity was very high.

(c) Experiment similar to VIII (a) was repeated on a single subject (the investigator) for 8 times on separate days to check the reliability of the results. In all the 8 trials (16 adaptation tests) X. was consistently more than X, . The mean values of X. and X_b were:15.93 (S.D = 1.21) and 10.62 (S.D = 1.08) respectively. Xb was measured using 1 KHz tone at 110 dB SPL for 7-min. Xh was measured at 120 dB SPL

Experiment IX

(a) 32 subjects (21 F + 11 M) ranging in age from 19 to 22 Yrs (Mean age = 21,1) showed mean adaptation values of 3.52 (S.D = 2.97) and recovery time varying from less than 1-min. to 3-min. for 0.5 KHz presented for 3-min. at 115 dB SPL. Nearly 50% of the subjects showed complete recovery within a minute. This experiment was done to have normative data regarding recovery time from adaptation to 0.5 KHz tone. This data might be useful if a diagnostic test based on recovery time for detecting retro-cochlear pathology cases would prove to be feasible.

(b) To study the 'frequency effect' in recovery time from adaptation, 1 KHz and 0.5 KHz tones at 125 dB SPL for 7-min were used for adaptation. Mean adaptation values (6 trials on the same subject - the investigator) for 1 KHz and 0.5 KHz were: 20.83 (S.D= 1.18) and 15.41 (S.D = 0.93) respectively. Recovery time for 1 KHz and 0.5 KHz in the above adaptation experiments were :> 5 < 7-min and> 2 < 4-min respectively. This result showed that the recovery was rapid at 0.5 KHz.

(c) To study whether the recovery time, like adaptation (X_L),was shorter when the recovery time was determined using a test tone at a level lower than the adapting intensity, 1 KHz tone at 125 dB SPL for 7-min was used as the adapting stimulus. Recovery time was measured at 110 dB SPL and 125 dB SPL separately. The recovery time in all the 5 trials (on the same subject - the investigator) was > 2 < 3-min. when it was measured at 110 dB SPL; whereas the recovery time was > 5 < 7-min when it was measured at 125 dB SPL (8 trials on the same subject). This result showed that like X_L recovery time measured at an intensity lower than the adapting intensity was also reduced; hence, this finding supported Small's prediction with respect to recovery time also.

Test-retest data of all the above experiments showed very high correlation (Significant at 5% level of confidence). The results of all the above experiments led the investigator to propose a revised model for loudness coding during auditory adaptation.

The essence of the revised model and its possible applications are listed here:

1. The adapted neural units are of three types: (1) Stable adapted neural units (a) (2) Positive unstable adapted neural units (+ -a'), and (3) Negative unstable adapted neural units (- -a').

7. For high stimulus intensities, loudness is determined by the total number of activated neural units from the following/(1)'Simple Category' (or 'Complex Category'), (2)(NIIH) and (3)(NIOH)**.

8. For low or moderate intensity stimulus, loudness of the post determined by the total number of activated neural , units from 'Simple Category' (or 'Complex Category') and (NIOH)**.

9. Possible mechanisms of loudness adaptation can be summarized as follows :

When a stimulus (1 KHz) of moderate intensity is continuously presented to one of the ears of a normal hearing subject, the adaptation process(i.e., a gradual and <u>continuous</u> decrease in the number of activated neural units) begins in the 'Simple Category'. This process goes on as long as the adapting stimulus is continued; hence (a) will be increasing. Simultaneously, with the adaptation process, the number of activated NIOH) units gradually <u>increases</u> as long as the adapting stimulus is continued i.e., (-a') will be increasing. This process is known as negative adaptation (or reverse adaptation). As the adapting stimulus is continued, more and more number of (NIOH) units begin to fire nerve impulses. Initially the rate of <u>decrease</u> in the number of activated neural units in the 'Simple Category' will be

---

**sensory units activated by the different system innervati
the outer hair cells.

2. 'Simple Category' and 'Complex Category' (terms used by Frishkopf and Goldstein) may be the sources for (a) units i.e., (a) units originate from the place of maximum stimulation of the basilar membrane, (a) units for low frequencies originate from 'Complex Category' and (a) units for 1 KHz originate from 'Simple Category'.

3. The source of (+ a') units is the Neural Units Innervating the Inner Hair Cells (NIIH) and they are produced as a result of the efferent action
4. The source of (-a') units is the Neural Units Innervating the Outer Hair Cells (NIOH) and they are produced as a result of the efferent action
5. (-a') units perform a reverse function of (+a') units and also that of (a) units. In other words, (-a') units (responsible for negative adaptation) will be contributing to the loudness during the adaptation process. (+a') and (-a') may be linked to 'R_2' and 'R_1' processes (respectively) reported by Hirsh and Bilger in connection with 'bounce' phenomenon observed within 2-min, of recovery time during TTS experiments. The revised model corroborates Hirsh and Bilger's hypothesis that 'bounce' phenomenon is a Neural phenomenon.
6. (+a') and (-a') units regain their original preadapted state whenever a test tone at an intensity higher than the adapting intensity is presented during the post adapted state.

faster than the rate of <u>increase</u> in the number of activated neural units of NIOH,. After dome time, the rate of increase in NIOH units will 'catch-up' with the rate of decrease in the number of activated units of the 'Simple Category'. As a consequence of this, the total number of nerve impulses contributing to the loudness of the adapting stimulus (or test tone at the adapting intensity) remains fairly constant (contribution of nerve impulses from the 'Simple Category' will be decreasing, but the contribution of nerve impulses from the NIOH will be <u>increasing)</u>. This way asymptotic loudness adaptation can be explained.

Incidentally, the above description, reveals a 'vital' information about 'inhibition' process. 'Inhibition' process in the auditory system is poorly understood. The revised model appears to be a 'break-through' in psycho-acoustic and electrophysiological research as far as understanding the mechanisms of 'inhibition' process in the auditory system is concerned Since (-a') units are responsible for inhibiting the adaptation process, phenomenon of negative adaptation can be viewed as 'inhibition' process. Added to this, we know that outer hair cells are innervated by Olivo-cochlear bundle which is known to be responsible for 'inhibition' process. Hence,now the mechanism of 'inhibition' process appears to be clear. While understanding the adaptation process, we have come to know the mechanism of 'inhibition' process which was not well understood and also our lack of knowledge regarding the 'inhibition' process was a great hurdle for understanding the complex mechanism of auditory processing of complex sounds.

detector

The auditory feature/theory of speech perception, which was not widely accepted because of our lack of knowledge about 'inhibition' process, perhaps, now, gains its 'due' recognition.

10. X_h depends on (a) units only,

11. X_b depends on (a), $(+a^1)$ and $(-a^1)$.

12. X_L depends on (a_l) , (^+a_l) and $(-a_{l)}$

** <u>Derivations</u> ,- $A = (a) + (a^1)$ - eq.1

(See P X X *iv)* $L_{tbb} = A + u$ - eq. 2

for abbreviations -$L_{tba} = u$ - eq.3

X_b = Eq. 2 - eq- 3 = $A = (a) + (a')$

$X_b = (a) + (a^1)$ - eq. 4

$L_{tbb} = E + A + U$ - eq. 5

$L_{tha} = E + a' + U$ - eq.6

X_h = eq. 5 - eq. 6 = a

$X_h = a$ - eq. 7

$L_{tlb} = A_l + U_l$ - eq. 8 (.. Small's prediction)

X_l = eq.8 - eq.9 = $A_l = (a*) + (a£)$

$X_l = (a_l) + (a_l)$ - eq.1O

13. The effect of (a) units can either be enhanced by (+a') units and/or decreased or cancelled by (-a') units. In other words, the loudness loss brought about by (a) units can be aggravated by (+a') units and/or the loudness loss can be minimized or completely cancelled or the loudness can be increased by the action of (-a') units.

14. The revised model can be used to explain the different results which are observed in adaptation measurements. The necessary conditions for the different results are given below:

(a) $X_h > X_b > 0$

$a > a + a' > 0$

(1)
Necessary conditions (NC)/$a^1 < 0$ and (2) $a > -a'$

(b) $X_h > {}^{x}b = 0$

$a > a + a' = 0$

Necessary conditions (NC) (1) $a^1 < 0$ and
(2) $a = -a^1$

(c} $X_h > X_b^{<0}$: $a > a + a^1 < 0$

The necessary conditions: (l) $a^1 < 0$ and (2) $a < -a^1$

Id) $X_h = X_b = 0$; $a = a + a^1 = 0$

The necessary conditions: (l) $a^1 = 0$ (2) $a = -a^1 = 0$
This result was not observed in any of the subjects,

(e) $X_h < X\wedge = 0$; $a < a + a^1 = 0$

The necessary conditions: (l) $a' > 0$ (2) $a = -a^1$
This result was not observed in any of the subjects,
as the two conditions could not be satisfied.

(f) $X_h < X_b > 0$; $a < a + a^1 > 0$.

The necessary conditions; (l) $a^1 > .0$ (2) $a > -a^1$ and (3) $a > 0$.

(g) $X_h < X_b > 0$; $a_l + a_l < a + a^1 > 0$

The necessary conditions: (l) $a_l + a_l' < a + a^1$ (2) $a > -a^1$

15. The revised model can be used to explain the available data for simultaneous Dichotic Loudness Balance Method (SDLB). As the revised model is derived from a Monaural technique, the model should be applied to each ear separately.

Xb (SDLB) > Xb (Monaural Hetrophonic - MH) is due to 'binaural interaction'. The 'binaural interaction' can be defined as the efferent action of monaural stimulation on the periphery of the contralateral auditory system.

Xb (at 60 dB) in SDLB = Xb (at 80dB) in SDLB = 20 dB (the data reported by Weiler et al), is due to a phenomenon which may be named—the 'eclipse phenomenon'. The 'eclipse phenomenon' is the phenomenon in which the increase in the amount of adaptation which should result in the adapting ear, due to the increase in the intensity of the adapting stimulus (i.e., increasing the intensity from 60 dB to 80 dB SPL) is 'eclipsed' by the combined actions of the two efferent systems (the efferent systems innervating the outer hair cells and the efferent system innervating the inner hair cells) in the comparison ear. The action of the efferent system innervating the outer hair cells is to increase the loudness of the post adapted test tone in the comparison ear and the action of the efferent

---

* This point is revised in the light of an alternative approach available to the problem concerned.

system innervating the inner hair cells is to decrease the loudness of the post adapted test tone in the comparison ear. When the adapting stimulus is at 80 ds SPL in the adapting eR, there will be a combined action.of the efferent.systems in the comparison ear which results in

$*a^1$ = *Ltbb = Ltbb.

$X_h < X_b > 0$ at 60 dB SPL adapting intensity in SDLB,is due to the fact that Xb will be greater as a result of 'loudness gain' in the comparison ear (binaural interaction) where as this 'loudness gain' will be absent during Xh measurements (when the post adapted test tone is presented at an intensity higher than the adapting intensity the efferent action (cases).

$X_h < X_b > 0$ at 80 dB SPL,adapting intensity in SDLB, is due to the combined efferent actions in the comparison ear and the adapting ear, together with the cessation of efferent actions during Xh measurements.

16. The revised model can also be used to explain the available data of Monaural Heterophonic (MH) technique. MH technique yields $X_h = X_b > 0$. As per the revised model, the necessary conditions for this result are: (1) $a' = 0$ (ii) $a > -a'$. These conditions are responsible for the above result. The result :$X_h < X_b > 0$,

can also be expected in MH technique, provided the adapting intensity is very high. The necessary conditions for $X_h < X_b > 0$ are : (1) $a' > 0$ and (2) $a > -a'$. These conditions can be expected only at very high adapting intensity.

The available data show that MH technique yields significant adaptation (= 2 0 dB) for adapting stimulus 90 dB SPL, in contrast to other monaural techniques. The revised model shows that 'u' units for low frequencies and high frequencies are derived from 'Complex Category' and 'Simple Category' respectively. This difference enables the subject to make relative loudness judgements in MH technique during preadapted as well as post adapted balances. The other monaural techniques do not provide this advantage to the subjects; for instance, the technique which requires the subject to adjust the intensity of a continuously presented tone so as to maintain it at constant loudness. It is known that human sensory communication system is less than 0.1% efficient than an ideal communication system. This poor performance is due to the fact that our sensory systems are very poor in absolute judgements. Probably this factor might be responsible for the failure of the monaural techniques to show significant adaptation (Concomitant).

17. The important clinical applications appear to be that the present technique can be used as a special test

ABBREVIATIONS

A. Adaptable/Adapted neural units at the adapting intensity (base-line condition).

a Stable adaptable/adapted neural units.

$+a^1$ Positive unstable adaptable/adapted neural units.

-a' Negative unstable adapted neural units.

L_{tbb} Loudness of a test tone at the adapting intensity (basse-line condition), before adaptation-.

L_{tba}. Loudness of a test tone at the adapting intensity (base–line condition) after adaptation.

L_{tlb} Loudness of a test tone at a level higher than the adapting intensity, before adaptation.

L_{thl} Loudness of a test tone at a level higher than the adapting intensity after adaptation.

$L_{t\downarrow b}$ Loudness of a test tone at a level lower than the adapting intensity, before adaptation.

$L_{t\downarrow a}$ Loudness of a test tone at a level lower than the adapting intensity, after adaptation.

X_b Adaptation, "measured at the base-line condition or adaptation measured at the adapting intensity or 'Simple' - adaptation.

X_h Adaptation measured at an intensity higher than the adapting intensity,

Al Adaptable/adapted neural waits at a level lower than the base-line condition.

$a_{\downarrow}$ Stable adaptable/adapted neural units at a level lower than the base-line condition.

$+a'_{\downarrow}$ Positive unstable adaptable/adapted neural units at a level lower than the base-line condition.

$-a'_{\downarrow}$ Negative unstable /adapted neural units at a level lower, than the base-line condition.

u- Unadaptable/unadapted neural units at the base-line condition.

E- Extra neural units activated by. the test tone higher in intensity than the test tone at the adapting intensity.

$X_{(b\text{-}IA)}$ - Adaptation measured in-the comparison ear at an intensity equal to the adapting intensity. (Adapting intensity in the comparison ear = adapting intensity in the adapted ear - Interaural Attenuation for A/C), in clinical audiology for detecting retrocochlear pathology and cochlear pathology cases. Measurement of recovery time from adaptation and negative adaptation using the present technique, would enable the audiologists to have important information regarding the possibility for the presence or absence of retrocochlear pathology and also about the integrity of 'Low-threshold' mechanism.

To conclude, the revised model for loudness coding during auditory adaptation, answers most of the controversies prevailing in the area of auditory adaptation. It is hoped that the revised model would act as a 'Catalyst' for rapid advancement of research in auditory physiology and 'Neuro-sciences' as the model has revealed the mechanism of 'Inhibition' process which was a 'Mystery' till date.

CHAPTER I

INTRODUCTION

Nearly two-decades ago, Small (1963) wrote that, "the stumbling block to the study of loudness adaptation has been and still is the lack of a straight forward technique of measurement". A thorough review of the literature concerning auditory adaptation, reveals that not much progress has been mad over all these years interms of developing a 'straightforward technique' for the mesurment of adaptation; hence, the area of loudness adaptation is full of controversies. studies relating to the amount of adaptation as a function of intensity, duration and fraquency of the stimulus are in confliet. Recently Weller and Friedman (1973); Weiler and Gross (1976); and Feaster and Weiler (1975) have reported significant positive adaptation using a monaural technique viz., Monaural Heterophonic (MH). On the contrary, a number of stuies (Bray, Dirka and Morgan, 1973; Dirks, Morgan and Bray, 1974; Fraser, Petty and Elliott, 1970; Mirabella, Taub and Teichner, 1967; Petty, Fraser and Elliott, 1970; stokinger, Cooper and meissner, 1977; Stokinger and Studebaker, 1968; Wiley, Small and Lilly, 1973) have suggested that the adaptation effect could be attributed to binaural interaction-implying that if the test conditions were designed to eliminate lateralizing effects and binaural interaction between adapting and comparison tones, supra-threshold adaptation would be absent.

The above controversy exists mainly because of non-availability of a 'straightforward technique' for the measurement of adaptation.

A new objective technique viz., Objective Residual Monaural Loudness Adaptation (0RMLA) was developed (Vyasamurthy*, 1977) to study the phenomenon of leudness adaptation. The new technique satisfies most of the criteria laid down by Small (1963) for the measurement of 'adequate' adaptation.

The thesis++ deals with adaptation measurment using ORMLA technique.

Gorga, Lilly and Length (1980) have provided evidences for both qualitative and quantitative similarities between acoustic reflex and the perception of loudness and they have concluded that signals at the threshold of acoustic reflex may be equally loud for listeners with normal hearing, Block and Wiley (1977) have suggested that a relation between loudness and acoustic reflex response may exist if signals are equated interms of the magnitude of the middle ear muscle response. Block and Wrightman (1977); Bwertsen at al (1958);

---

* See Appendix A

++Portions of this study were presented, at the IX Annual conference of Indian Speech and Hearing Association, held at bangalore during Jan. 1977. under the title: "Objective Verification of Small's Model of Loudness Adaptation", (this paper get Dr. Desa's Best Paper Award).

Flottorp et al. (1971); and Jepsen (1963), have presented evideness that the acoustic reflex is directly related to the loudness experience of the subjects. Further, Fedman (1963); Jepsen (1963); Kristensen and Jepsen (1952); Lamb et a1, (1968); Metz (1946); and Thomsen (1955), have prasented evidence that the occurrence of the reflax at a reduced sensation level reflects loudness recruitment. However thare are studies vlz., Anderson and Barr (1966); Scharf (1976); and Martin and Brunette (1980), which contend that the acouatic reflex may not depend exclusively on the perception of loudness. This controversial issue has been diacussed thoroughly by Gorga et al (1980).

The investigator, fully agrees with Gorga and his co-investigatore' (1980) general conclusion: "the hypothesis that signale at TAR (Threshold of the Acoustic Reflex) are equally loud cannot be dismissed. The results from the present experiment indicate that some relation (between loudness and acoustic reflex) exists.... Finally, measurements of psychophysical critical band widths may be dependant upon the intensity at which these measurements are made".

In addition to the evidences provlded by Gorga et al., (1980) and Block and Wiley (1977) in support of the relationship between loudness and acoustic reflex, the investigator studied the magnitude of reflex (as indicated by the deflection of the Balance Meter needle of an electro-acoustic impedance bridge-Madsen Z0 73) in 8 normal hearing subjects for three different pure tones viz., 500, 1000 and 2000 Hz at 120 dB SBL. The results showed that the magnitude of reflex in each subject was exactly the same for 500 and 1000 Hz tones at 120 dB SPL—-implying that the magnitude of reflex was an indirect 'measure' of loudness perceived.

Above all, Borg and Odman (1979) have confirmed that decay and recovery originate in the afferent auditory system and not in the acoustic reflex muscles.

In the light of the evidences provided by Gorga et al., (1980); Block and Wiley (1977); Block and Wightman (1977); and the experimental evidence provided by the investigator, it may not be unreasonable to assume that there is a relation between loudness and acouetic reflex response in normal hearing subjects, if signal-—500 and 1000 Hz-- are equated in terms of the magnitude of the middle ear muscle response. In other words, in a normal hearing subject , pure tones viz., 500 and 1000 Hz at equal loudness would produce the same magnitude of reflex (as indicated by the stiffnese changes of the middle ear system when an electro-acoustic impedance bridge with a probe tone of 220 Hz is used). In the present study, a calibrated Madsen Z0 73 impedance bridge warn used for observing the changes in the magnitude of reflex (See Appendl-B for details regarding the Madsen - Z0 73 instrument).

As a point of clarification regarding the measurement of stiffness changes of the middle ear system, the explanation given by Kaplan et al (1974) can be mentioned: "At a probe frequency of 220 Hz, the Madsen instrument measures only the magnitude of the impedance changes regardless of whether the change is reaistive or reactive, The measured impedance magnitude at the low frequency is primarily determined by the reactive rather than by the muscale's smaller resistive components of the middle ear impedance. For example, using representative middle ear impedance values of 1500 Ohms reactance (X_A) and 300 Ohms resistance (RA) the magnitude of the middle ear impedance ($|Z_A|$) is 1560 Ohms.

$$Z_A = X_A 2 + R_A 2 = 1500^2 + 300^2 = \underline{1560}$$

RA contributes only 4% of the total impedance magnitude".

Ward (1973) distinguishes the phenomena commonly included under adaptation in two different ways: whether they are observed during or after exposure to the acoustic stimulus (concomitant or residual respectively) and whether they require one ear (Monaural) or two (Binsural) for their measurement, Example for these four categories--concomitant monaural, concomitant binaural, residual monaural and residual binaural-—are: tenedecay, perstimulatory adaptation, TTS and Loudness reduction (measured by ABLB teat) respectively.

In the present study, loudness adaptation was measured after exposure to the acoustic stimulus and It was measured using one ear—-the adapted ear. The measurement of adaptation was made objective useing a calibrated electro-acoustic impedance bridge. The non-test ear was used just for monitoring the stiffness changes. The adapting stimulus was always presented to the left ear of normal hearing (≤ 20 dB HL, ANSI, 1969) subjects and monitoring of the reflex was done in the right ear (air-pressure in the right ear canal was always set at Omm-water). The changes in the magnitude of tbo reflex rosponse (stiffness changes of the middle ear system) as indicated by the deflection of the Balance Meter (BM) needle of a calibrated electro-acoustic impedance bridge Madsen 2073 were noted down at dlfferent intensities of the test tone before adapting the ear. Consistent 'BM readings' at different intensity levels of the test tone were noted, The inter-stimulus interval was 30-sec for test tones

< 100 dB SPL and 60-sec for test tones 100 dB SPL. The duration of each presentation of the test tone was 1.5 sec. After noting down the 'BM reading' for the test tone at different intensity levels, the probe tone (220 Hz) in the probe ear (right ear) was put off. Then, the adapting stimulus was presented continuously (duration, intensity and frequency of the adapting stimulus varied depending on the type of experiment). At the end of the required duration of exposure of the adopting stimlus, the adapting stimulus was withdrawn and after 5-sec rest period, (this rest period was required for setting the controls of the impedance bridge) the test tone at a level depending on the type of the experiment was presented for 1,5-sce. The 'BM reading' was noted down. This reading was compared with the 'BM readings' of the pre-adapted test tone levels. The pre-adapted test tone level which bad produced the same 'BM reading' (magnitude) of reflex) as that of the post-adapted test tone, was identified. Adaptation (in dB) was the difference between the post-adapted test tone level and the pre-adapted test tone level which produced the same 'BM reading' as that of the post-adapted test tone, this way, loudness adaptation was measured in decibels (dB) objectively. Loudness adaptation measured in tbe above manner has been termed 'Objective Residual Monaural Loudness Adaptation' (ORMLA).

'BM reading' for pre-adapted test tone levels were recorded prior to each adaptation test. A minimum of 24 to 48 hours rest, between adaptation tests, was allowed for each subject to ensure complete recovery from the fatigue processes.

the procedure for finding recovery time from adaptation was exactly same as the procedure used for measuriag adaptation, but with a little difference. The measurement of adaptation did not stop at single presentation of the test tone (for 1.5-sec), 5-sec after the withdrawal of the adapting stimulus. The test tone was repeatedly presented once in 60-sec for 1.5-sec and each time 'BM reading' was noted. This procedure was continued until the 'BM reading' was the

same as the 'BM reading' produced by the test tone during pre-adapted condition (in experiments IXb and IXc recovery process was studied for 10-min of post adapted condition, the 'BM readings' obtained at 60-sec intervals were compared with the 'BM readings' which were recorded during pre-adapted condition to compute adaptation (in dB) at 60-sec intervals of recovery time.

The above brief description of the new technique (ORMLA) clearly shows that the reflex decay (or reflex adaptation) studies reported in the literature are quite different from tha present study. The reflex decay studies reported in the literature are concerned with 'concomitant' adaptation whereas the present study deals with 'residual' adaptation.

The present study was designed to verify the following null hypotheses, using 0RMLA technique:

1. Duration of exposure of the adapting stimulus has no significant effect on the amount of adaptation.

2. Frequeacy of the adapting stimulus has no significant effect on the amount of adaptation.

3. Frequence of the test tone has no significant effect on the amount of adaptation,

4. intensity of the adapting stimulus has no significant effect on the amount of adaptation.

5. There is no significant difference between the amount of adaptation measured at an intensity lower then the adapting intensity ( ) and the amount of adaptation measured at the bese-line condition or also known as adapting intenaity (X_b).

6. there is no significant difference between the amounts of adaptation obtained in the experimental oonditions A and B, where experimental condition A refers to the meaaurement of adaptation for 1 KBz tone at 100 dB SPL, after adapting the ear using 1 KHz tone for 7-min at 109 dB SPL and the experimental condition B refers to the measurement of adaptation for 1 KBz tone at 100 dB SPL after adapting the ear using 1 KHz tone for 7-min at 115 dB SPL.

7. There is no signicant difference between X_b and the the amount of adaptation measured at an intenaity higher than the adapting intensity (Xh).

In addition to the verification of the null hypotheses, the purposs of the preseat investigation was to find answers to the following question

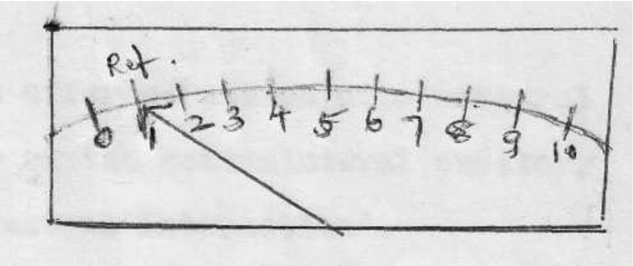
1. Are there differences in the 'magnitude of reflex' produced by the puretones viz., 0.5, 1 and 2 KHz at 120 dB SPL? (As per equal loudness contours these tones at 120 dB SPL are expected to be board equally loud in a normal hearing subject)
2. Does the 'frequence effect' (observed by many investigatora in adaptation studies) disappear if the adapting stimull are presented at equal loudness levels instead of constant intensity levels
3. Does the recovery time from adaptation vary depending on the frequency of the adapting stimulus?
4. Does the 'recovery time' from adaptation vary as a function of the intensity of the adapting stimulus?
5. Does the 'recovery time' from adaptation vary depeading on the intensity of the test tone used while measuring the recovery time?
6. Would it be possible to explain the controversics prevailing in the area of auditory adaptation using the data of the present study?
7. would it be possible to improve or revise the existing models for loudness coding during auditory adaptation using the data of the present study?
8. Would it be possible to use the present technique as a special test in diagnostic audiology for possible location of the lesions in the auditory system?

9. Would it be possible to throw some light on 'perstimulatory adaptation' as it is known as a 'provoking enigma' (Ward, 1973)?

10. In genral can the data of the present study provide a new insight into the mechanisms basic to auditory adaptation?

Definitions of same of the terms used in the present study

BM reading reference. Frior to the presentation of the test tone to the subject's ear, the Balance Meter needle is required to be adjusted to a reference value. In the present study, the reference reading used was '1' on the Balance Meter Scale.



'BM reading' (Magnitude of reflex). Balance Meter (BM) reading refers to the indication of the Balance Meter needle of the Madsen 20-73 (20-73) Impedance Bridge, on the Balance Motor Scale when the test tone is presented to subject's ear at his acoustic reflex threshold or at higher levels.

Adapation (ORMLA). Adaption (Objective Residual Monaural Loudness Adaption) in decibels, is the differeces between the post adapted test tone level and the pre adapted test tone level which had produced the same 'BM reading' as that of the post adapted test tone.

0R Adaptation (ORMLA) in dB = post adapted test tone level - pre adapted test tone level which had produced the same 'BM reading' as that of the post adapted test tone.

'Negative Adaptation'. 'Negative Adaptation' is said to be present whan 'BM reading' (magnitude of reflex) produced by the poet adapted test tone is greater then the pre adapted teat tone (pre adapted test tone level = post adapted test tone level). In negative adaptation, the loudness of the post adapted test tone will to greater than the loudness of the pre adapted test tone, although the intensity levels of the two tones are the same.

'Binaural Interaction: The efferent action of a monaural stimulation on the periphery of the contralateral auditory system is defined as the 'Binaural Interaction'.

The 'eclipse' phenomenon. The increase in the amount of adaptation, which should result in the adapting ear (in SDLB), due to the raise in the intensity of the adapting stimulus (i.e,, from 60 dB to 80 dB), is 'eclipsaed' by the combined actions of the efferent systems innervating the outer hair cells and the inner hair sells—the efferent systems have opposing functions. the levelling off of adaptation observed in simultaneoum Dishotic Loudness balance (SDLB) method can be explained by means of the 'eclipse' phenomenon.

ABBREVIATION

NIOH units.	Neural Units Innervating the Outer Hair Cells.
NIIH units.	Neural units Innervating the Inner Hair Cells.
A	Adaptable/Adapted neural units at the adapting intensity (base-line condition).
a	stable adaptable/adapted neural units.
+a'	Positive unstable adaptable/adapted neural units.
-a'	Negative unstable adapted neural units.
L_{tbb}	Loudness of a test tone at the adapting intensity (baseline condition), before adaptation.
L_{tba}	Loudness of a test tone at the adapting intenaity (baseline condition) after adaptation.
L_{thb}	Loudness of a test tone at a level higher than the adapting intensity, before adaptation.
L_{tha}	Loudness of a test tone at a leave higher then the adapting intensity, after adaptation'
L_{tlb}	loudness of a test tone at a level lower than the adapting intensity, before adaptation.
L_{tla}	loudness of a test tone at a leave lower than the adapting intensity, after adaptation.
X_b	Adaptation, mesaured at the base-line condition or adaptation mesaured at the adapting intensity or simple adaptation.

X_h Adaptation measuerd at an intensity higher than the adapting intensity.

X_l Adaptation measured at an inteneity lower then the adapting intensity.

A_l Adaptable/adapted neural units at a level lower then tae base-line condition.

a_l Stable adaptable/adapted neural units at a level lower than the base-line condition.

$+a_l'$ Positive unstable adaptable/adaptad neural units at a leval lower than the base-line condition.

$-a_l'$ Nagative unstable adaptad neural units at a leval lower then the base-line condition.

u_l Unadaptable/uaadapted neural units at the base-line condition.

u_l Unadapted/unadaptable neural units at a level lower than the base-line condition.

E Extra neural units activated by the test tone higher in intensity than the test tone at the adapting intensity.

$*x_{(b-IA)}$ Adaptation mearsured in the comparison ear at an intenaity equal to the adapting intensity. (Adapting intensity in the comparison ear = adapting intensity in the adapted ear - Interaural Attenuation for A/C).

CHAPTER II

REVIEW OF LITERATURE

The review of Literature concerning the present study deals with the three important research areas: (1) Loudness Vs Acoustic Reflex (2) Reflex Adaptation (or Reflex Decay) and (3) Auditory Adaptation).

LOUDNESS VS ACOUSIC REFLEX

Many studies (Jepsen, 1963; Dallos, 1964; Jerger et al, 1972; Peterson and Liden, 1972; Beedle and Harford, 1973; Margolis and Popelka, 1975; Kaplan et al, 1977; Margolis and Fox, 1977; Vyasamurthy and satyan 1977 wilson and Mc Bride, 1978) have shon that in normal hearing subjects, the threshold of the acoustic reflex for pure tones occure at levels of 70 - 90 dB HL (ISO,1964). Also many investigators (Metz, 1952; Ewetsen et al, 1958; Jepsen, 1963; Liden, 1969, 1970; Djupesland and Flottorp, 1970; Jerger et a1, 1972; sieminski et al, 1977; Popelka, 1978; Rangasayee, 1975) have reported that mild to moderate hearing loss of cochlear origin exhibit reflex thresholds for pure tones at 70 - 90 dB HL (ISO, 1964). Thus, it follows that the reflex occurs at raduced sensation levels in mild to moderate sensorineural loss (Cochlear Pathology) patients. "Qualitatively this effect is consistent with the abnormal growth of loudness that the patients demonstrate as the sensation level of a pure tone is increased. In fact, measurement of threshold of acoustic reflex has been referred to as the 'metz Test of Londness Recruitment' (Ewertsea et al. 1958) and elicitation of acoustic reflex activity at reduced sensation levels has been interpreted as an objective measure of recruitment of loudness". (Gorga et al, 1980).

ln addition to the above observation, there are studies (Anderson et al, 1969, 1970 a,b; Cartwright and Lilly, 1979; Olsen et al, 1975; Jerger, 1974; Sheehy, 1977) which show that the patients with confirmed retrocochlear pathology exhibit 50% reflex decay at suprathreshold levels. This effeot is similar stleast on a qualitative basis to the decay of loudness observed in these patients on psycho-physical tests such as tone decay (Gorga et al, 1980).

Further, many investigation (McCandles, 1975; Tonnison, 1975; Shon and McCandles, 1976; Rapport and Tait, 1976; Mc Leod and Greenberg, 1977; Woodford and Holmes, 1977)have used the acoustic middle-ear musicle response to estimate loudness discomfort level.

Ross (1968) compared equal reflex and equal-loudness contours. The level of each of eleven tonal activating signals was set to elicit the same reflex magnitude as a reference tone (320 Hz). Additionally, each signal was matebed in loudness to the 320 Hz reference. 2 of 4 subjects demenatrated similar equal-reflex and eqaul-loudness contours whereas the remaining 2 subjects demonatrated marked variations between the two measurements. Bleak and Wightman (1977) examined the relation between a statistically defined acoustic-reflex response and loudness for a 1000-Hz pure tone and for three different bands of noise. During loudness balances, each activating signal served as reference and was set at a level that yielded a specific magnitude of the middle-ear muscle response. The result from this study indicate a correlation between loudness and the acoustic reflex, Regardless of which signal served as the reference, equal-loudness contours approximated equal-reflex contours.

Block and Wiley (1979) examined acoustic-reflex growth functions and loudness balance judgements for 3 normal hearing subjects with normal middle ear function. The hypothesis that acoustic reflex activating signal producing proportionately equal acoustic impedance changes are judged equal in loudness, was evaluated. The mean acoustic impedance and associated standard deviations were computed for the baseline (static) and activator (reflex) portions of each reflex event. an acoustic impedance change exceeding 2 standard deviations of base line was defined as the criterion acoustic reflex response. Acoustic impedance was measured as a function of activator SPL for broadband noise and a 1000 Hz tone from oriterion magnitude to the maximum acoustic impedance (or 120 dB SPL). This was defined as the dynamic range of reflex growth. loudness-balance measurements ware made for the 1000 Hz tone and broad band noise at SPL's representing 30, 50 and 70% of the individual dynamic range. Tha data supported the hypothesis.

Gorga et al (1980) studied the effect of activating-signal band width upon the threshold of the acoustic reflex in normal hearing sutjects. Subsqueatly, loudness measurements were made for the same signals at the same intensity levels that were required to elicit an acoustic-reflex response. When loudness and acoustic reflex threshold were compared at comparable levels, similar trends emerged. They concluded that the results from that experiment provided evidence for both qualitative and quantitative similarities between acousatic reflez and the perception of loudness. Finally, on the basis of the resulte obtained, they suggested that signals at acouatic reflex thresholds may be equally loud for listeners with normal hearing.

Although, the above mentioned studies clearly point out that the loudness and acoustic reflex are closely related, there are also studies which point out that the acoustic reflex may not depend exclusively on the perception of loudness.

Small et al (1962) havo shown that loudness summation is somplete in approximately 20 m sec at levels of 60 dB sensation level. Although some difficultiea exist in the measurement of temporal integration for the acoustic reflex, available data suggest that the critical duration for acoustic reflex threshold is never shorter than 100 m sec(Gorga et al, 1980).

In 1975, Margolis and Popelka examined the hypothesis that loudness is constant at acoustic reflex threshold. Acoustic-reflex thresholds ware measured in five normal hearing adult subjects for octave frequancies from 250 to 4000 Hz, for a narrow band noise (BW = 50 Hz) centred at 500 Hz and for a wide-band noise. Acoustic reflex threshold was determined and the loudness of the reflex threshold stimulus was measured utilizing a monaural loudness-balance procedure employing a 1000 Hz comperison tone and a method of oonstant stimuli. Results indicated that for the activating stimuli used in that experiment, loudness at acouatic reflex threshold varied over a 17 dB range. They have concluded that the acoustic reflex is not dependent am some critical loudness of the activating stimuls and loudness may not be the key determinant of reflex activity."

Gorge et al (as reported by Gorga et al, 1980) investigated the acoustic reflex under binaural stimulation. They mesaured tbe magnitude of the acoustic reflex as a function of interaural phase for a 550-Hz tonal activating signal. the level of this signal was varied over a range of + 10 dB relative to its acoustic reflex threshold and warn always presented in a background of noise. They found that there was no dlffereacs in the magnitude of the acoustic-reflex response between homophasic and antiphsaic conditions even through the antiphasic condition was judged louder (or more easily detectable). Thus the above result rasied some doubts regarding one-to-one relationship between loudness and acoustic reflex.

"The literature concerned with the effects of signal bandwidth on loudness and on acoustie reflex threshold suggest that loudness and middle ear muscle response are not related, Many investigators (Zwicker et al, 1957; Scharf, 1959, 1962, 1976; Scharf and Meiselman, 1978) have studied critical band-widths for loudness under various stimulus conditions. Flottorp et al (1971), Djupesland and Zwislocki, (1973), Popelka et al (1974, 1976) and Djupesland et al, (1975) have reported band-width effects for acoustic reflex thresholds. The major differences between the findings in the above two classes of experiments is that the critical band-width' for the acoustic reflex is four to six times larger than the 3estimates of 'critical band width' from psycho-physical loudness measurements." gorga et al (1980).

The earlist models assumed that the width of the critical band for loudness was Independent of single level. It should be noted, however, that indications of same level effects exist in meat psycho-physical data on oritical band width for loudness (Gorga et al, 1980).

Bourbon et al, (1968) provided evidence from masking studies that measured critcal band widths may increase with level(as reported by Gorga et al,1980).

The above mentioned studies show that there may not be one-to-one relationship between loudness and acoustic reflex.

Thus the relationship between leudness and acousatic reflex, has became a controvarsial issue. However, the present investigator completely agrees with the views expressed by Gorga et al (1980) regarding the relationship between loudness and acoustic reflex. Gorga et al,(1980) have thoroughly discussed this matter:

> ... the argument that loudness and TAR (Acoustic Reflex Threshold) are unrelated cannot be based solely upon a comparisom of the effect of signal band width on the two measured responses, The data from the present emperiment suggest that both loudness and TAR are affected in a similar manner by changes in band width....
>
> ....
>
> ... some general conclusions seem appropriate. The hypothesis that signals at TAR are equally leud cannot be dismissed. The results from the present experimemt indicate that some relation exists. Additionally, the frequency analysis for both TAR and loudness appear to be similar, at least in form. Finally, measuremants of psycho-physical critcal band widths may be dependent upon the intensity at which these measurements are made.

As mentioned earlier, the present suthor goes by the general conclusions of Gorga et al, (1980) with regard to the relationship between loudness and acoustic reflex. In addition to this, the results of the experiment I (see page 68) led the investigator to use the 'magnitide of reflex' as an indirect measure of loudness perceived by the normal hearing subjects.

REFLEX ADAPTATION (OR REFLEX DECAY)

Acoustic Reflex Adaptation is a relatively new area of investigation. adaptation of the acoustic reflex refers to a decrease in the magnitude of the reflex response during sustained acoustic stimulation. several investigation have described aspects of this phenomenon (Lorento de No', 1935; versall, 1958; Dallos, 1964; Djupesland, Flottorp aad Winther, 1967; Anderson, Barr and Wedenberg, 1968; Habener and Snyder, 1974; Olsen, Noffsinger and Kureziel, 1975; Wiley and Karlovich, 1975; Cunningham, 1976; Kaplan, Oilman and Dirke, 1977; Wilson, steckler, Jones and Margolis, 1978; Hetu and Careau, 1977; Given and seideman, 1979),

Anderson, Barr and Wedenberg (1969, 1970) have suggested that the measurment of acoustic reflex adaptation is an indication of VIII cranial nerve integrity. They have also indicated that the amount of acoustic reflex adaptation relative to the maximum reflex contraction observed could be useful in diagnostic clinical audiology. They have suggested that 50% reflex decay is a critical level for interpretation of clinlcal significance. In brief, the procedure involved in determining 50% reflex decay is— presentation of a 10 see pare tone stimulus at 10 dB SL (re: acoustic reflex threshold), at frequencies of 500 Hz or 1000 Hz and noting down the reduction in magnitude of reflex during 10-sec period. The reflex decay test is said to be positive of 50% reflex decay occure within 5-sec of presentation of the stimulus. anderson et al, (1970) have indicated that when this procedure was applied with stimulus frequenceis of 2000 and 4000 Hz, considerable adaptation was noticed in normal hearing subjects. Therefore, they recommended that the frequensies above 1000 Hz should not be used for the clinical measurment of acoustic reflex decay for inference of VIII nerve integrity.

Johansson, Kylin aad Langly (1967) observed no reflex adaptation to stimuli of 500 or 1000 Hz for 14 sec at 10 dB SL (ref; acoustic reflex threshold) in normal hearing subjects. However, they observed 50% reflex decay in normal hearing subjects to a stimulus of 2000 Hz at a sensation level of 10 dB SL (ref: acoustic reflex threshold) in 14 sec.

Similar 50% reflex adaptation was observed in 7 sec for a reflex eliciting stimulus of 4000 Hz.

Habener and Snyder (1974) reported no significant reflax adaptation to 500 and 1000 Hz reflex eliciting stimuli at 10 dB SL (ref:acoustic reflex threshold) in all 120 normal ears testsed significant reflex adaptation, however, was observed at 2000 and 4000 Hz. Thier data agreed with the studies of Anderson et al (1970) and Johansson et al (1967).

Wilson, Steckler, Jones and Margolis (1978) reported an investigation of acoustic reflex adaptation in 7 normal hearing adults for the reflex eliciting stimuli of 300, 1000, 2000, 4000 Hz and broadband noise. Levels of 96, 104 and 112 dB SPL were used to achieve acoustic reflex. They comcluded that, "the higher the stimulus frequency, the greater the rate of reflex adaptation ...half life varies directly with stimulus intensity and inversely with stimulue frequeney".

Wiley and karlovioh (1979) reported the amount of reflex decay for 500 Hz at levels of 5, 10 and 15 dB SL (ref:acoustio reflex threshold). These investigators observed less adaptation at 5 dB SL than at 10 dD SL for signal duration of 3 to 5-min and rapid reflex adaptation at 4000 Hz, General

finding were that:

> ...the amount of reflex adaptation varied with the spectrum of activating signals (reflex adaptation warn greatest for the 4000-Hz activator less for the noise activator, and least for the 500-Hz activeing signal)... the rate of reflex adaptation differed with activator spectrum (reflex adaptation rate was relatively rapid for the 4000 Hz activator, slower for noise, and much slower for the 500 Hz activating signal.... reflex adaptation did not appear to vary systemmatically with activating signal level except for the 500 Hz activator. in which case reflex adaptation appeared to begni earlier in time and to be of greater magnitude as the activating signal level incrased.

The result of their study agreed with the results reported by Anderson et a1 (1970) and Alberti and Kristensen (1972).

Kaplan, Gilman and Dirks, (1976) investigated acoustic reflex adaptation in six normal subjects for five frequencies (500, 1000, 2000, 3000 and 4000 Hz) at senaation levels of 6, 12 and 18 dB. Kaplan et al (1976) reported no difference in the shape of the adaptation curves (% impedance changs relative to stimulus duration) at may frequency for the entire range of senastion level* tested. This is not consistence with the findings0 of Anderson et al (1970) or Wiley and Karolrich (1975).

Givens and Seidemen (1979) reported a systematic investigation of measurement parameters of acoustic reflex adaptation, Genral conclusion were that:

> ..study demonstrated properties of acoustic reflex adaptation that are in agreement with the previeus research of Anderson et al, 1979; and Wilson et al 1978. However, farther definition of the stimulus variables involved in the Anderson et al (1970) procedure was achieved The finding indicate that the aensation level - ref:acoustic reflex threshold affects proparties of acoustic reflex adaptation. How= ever, this effect is not intansity specific a range of 10 dB (15 dB + 5 dB) seems to be reasonable for this measurement Expect for 3000 Hz, stimulus frequency affected adaptation characteristics uniformly across sensation 1eve1. For 500, 1000 and 2000 Hz an inverse relationship was demonstration between adaptation and sensation levels. At 3000 Hz, a consistent level of 50% adoptation was noted at all sensation levels
>
> This study made the following implications on acoustic reflex adaptation in normal ears:
>
> (1) a range of at least 10 dB (15 dB SL 5 dB) is availabla for the asministration of the procedure:
>
> (2) stimulus frequency has asignificant effect on acoustic-reflex adaptation. Test stimuli should be selected with consideration of this variable.
>
> Further research is needs to investigate acoustic-reflex adaptation with cochlear and ratrocochlear pathologies. Additional studies are needed to develop a more definitive clinical protecol.

Stelmachowicz and Lilly (1979) reported an Indirect estimate of auditory frequency selectivity from acoustic reflex measurements. they used the following rationale far their investigation:

> ...Generally it has been assumed that the dynomic properties of the acoustic stapedial reflex are dependent, in part, upon the neural activity in the superior olivary complex (Blevins, 1967; Borg, 1973). In human subjects it is possible to monitor changes in stapedial reflex activity utilizing aural acoustlc

immittance measurements (Metz, 1951; Mollar, 1962; Dallos, 1964). Frequencies selectivity of the acoustic reflex, however, has not been studied systematically in man.

In order to determine the frequency resolution of the stapedial reflex, a method similar to that used in a classical psycho-physical adaptation paradigm was chosen. In this paradigm, changes in aural acoustic susceptance (BA) produced by various stimuli were recorded both prior to and immediately following the presentation of an adaptor signal, the choice of this paradigm requires the following three assumptions:

(1) An auditory stimulus of a given frequency and sound-pressure level excites a specific array of receptors;

(2) If stimulus level and duration are such that some degree of acoustic-reflex adaptation (decay) occurs, than the spectral spread of this adaptation may be used to determine frequency resolution;

(3) The extent to which the adaptation process decreases reflex-response magnitude (as a function of frequency) may be taken as a measure of the frequency selectivity of the system;

Unfortunately, there are a number of constraint and limitation inherent to this procedure. First, in order for the criterion response to be measurable some finite degree of acoustic-reflex adaptation must occur. In subject with normal hearing, however, Acoustic reflex adaptation typically is seen only at frequecies above 1000 Hz (Andorson, Barr and Wedenberg 1970; Cartwright and Lilly, 1978). In addition, within the frequency range where acoustic-reflex adaptation does occur, the rate of adaptation decreases with decreasing frequency (Kaplan, Gilman and Dirks, 1976). Thua, for low-frequency stimuli, adaptor duration must be longer then for high-frequency stimuli in order to observe a similar amount of adaptation.

A second concern involves the intensity levels that must be used in order to elicit an acoustic reflex. A number of investigators have reported intensity effects in other estimates of frequency selectivity (Bourbon, Evans, and Deatherage, 1968; Zwicker, 1974; Moore, 1978). Others, however, have failed to show these level effects

(Zwicker, Flottorp, and Stevens, 1957; McGee, Ryan and Dallos, 1976; Scharf and Meiselman, 1977, Weber, 1978). If intensity effects do exist, then the results from the present investigation only can be compared with data obtained at simllar levels.

Third, the present paradigm does not produce data in a form that is quantitatively comparable to existing estimates of frequency selectivity. Qualitative comparisons, however, are possible. To the exteat that neural activity in the afferent branch of the acoustic-reflex are is related to peripheral frequency analysis, simllar treads in data of the present experiment are expected.

They found that the recovery from acouatic-reflex adaptation was more rapid for test frequencies below the adapter frequency than for test frequencies above the adaptor and that when their data were compared to tone-on-tone masking functions, qualitative similarities emerged between frequency selectivity observed psyeho-physically and those observed during measurement of acoustic-reflex activity.

Nellis and Wiley (1979) have reported recovery characteristics of the acoustic reflex. They measured acoustic-reflex recovery time as a function of activator intensity level and duration for broad-band noise and a 500Hz tone in 10 mormal-hearing subjects. the activating signals were presented at 5 and 10 dB above individual acoustic reflex thresholds for durations ranging from 0.25 to 100 sec, Reflex-recovery times were simllar across both activators and across activator intensity levels. Recovery time was relatively constant for activators of 2 sec or less and incressed for longer activator durations. they have explained portions of the results from temporary threshold shift experiments on the basis of acoustic reflex recovery charateristics.

Borg and 0dman (1979) hava reported tha time course of decay and recovery of ipsilataral and contralsteral stapedius reflex especially to 2 KHz tone in 10 normal hearing subjects They found that the raflax rasponsas followed a closely similar time coursa with raspect to both dacay and racovery in simultaneous bilataral recording. They hava conoluded that dacay and racovery originate in tha afferant auditory system and not in the muscles. Thay found that the recovary was 50% complete, 250 m sec aftar the end of the stimauli.

Tha above mentioned studies ara quite different from the prsent study as most of those atudies deal with 'concomitant' adaptation (the present study deals with 'residual' adaptation). In addition, all tha raflax adaptation studies hava measured "adaptation" in terms of reduction in tha 'magnitude of raflex'. Whareas in the present study, adaptation (rasidual was measured in <u>decibels</u>.(although the 'magnitude of raflex' was the criterion used for estimating 'loudness loss' or *loudnss gain')

AUDITOR ADAPTATION

Auditory adaptation in its most general sense could be taken to refer to any change in the funotional state of the auditorysystembroughtaboutbyanacousticstimulus. Such a change in the auditory system's functional state may manifeet itself in a variety of ways (Small, 1963).

The loudness decrement resulting from continued auditory stimulation is termed auditory adaptation (Elliott and Praser, 1970).

"Auditory adaptation has as its essentiaal feature the process of 'equilibration'. The response of a receptor to a steady stimulus declines as a function of time until it reaches a stueady level at which the energy expanded by the receptor is just balanced by the metabolic eaergy which becomes available to sustain it. The psychological counterpart of this is a decline in apparent magnitude of a stimulus (e.g., its loudness) during the first few minites of presentation, followed by a period in which the apparent magnitude remains roughly coastant". (Moore, 1977).

A comprehensive review of loudness adaptation is provided by small (1963). small's (1963) model of loudness adaptation is reproduoced here (as the investigation consider it most relevant to the present study:

> ...the amount of loudness adaptation increases as a function of the intensity of the adapting stimulus. If adaptation is measured, however, at an intensity less than that of the adapting stimlus, it is found that the amount of adaptation does not depend upon the intensity at which the ear was adapted, but only upon the intensity at which adaptation is measured.
>
> Adaptation increases as a function of the duration of the adapting stimulus. The time taken for the adaptation function to reach asymptote depends upon the characteristics of the adapting stimulus, but rarely excesds 6 min. The amount of loudness adaptation decreases as a function of the interval between the cessation of the adapting stimlus and the presentation of the comparison stimuli. This recovery is monotonic with time and its rate depends upon the amount of adaptation from which recovery is taking place. The time taken for complete recovery varies tremendously with experimental procedure; it may be as short as 15 sec and almost certainly no longer than 4 min.
>
> Maximum loudness adaptation is found at the frequency of the adapting stimulus, but the spread of adaptation to other frequencies occurs in symmetrical fashion (on a frequency scale). In addition, the effect is a peripheral rather than a central phenomenon.

Possible Mechnisms of Loudness Adaptation

One way to view the effects of intansity upon adaptation is to postulate that a given group of receptors is not effected differentially by adapting stimuli of different intensity.There are a number of assumptions related to this postulate and it will be informative therefore to list the reasoning step by step. (1) The key assumption is that the neural coding for loudness is the number of fibers activated. (2) It ia also convenient to assume although not necessary in order to account for this intensity effect, that the neural elements have different sensitivities. (3) Presumably threshold constitutes some minimus numbar of active fibers, those with the lowest threshold and a 20 dB SL, stimulus for instance would, initially at least, activate a group of greater number. Figure 1a,schematizes this situation. (4) If the 20 dB SL stimulus is continued indefinitely, some of the neural

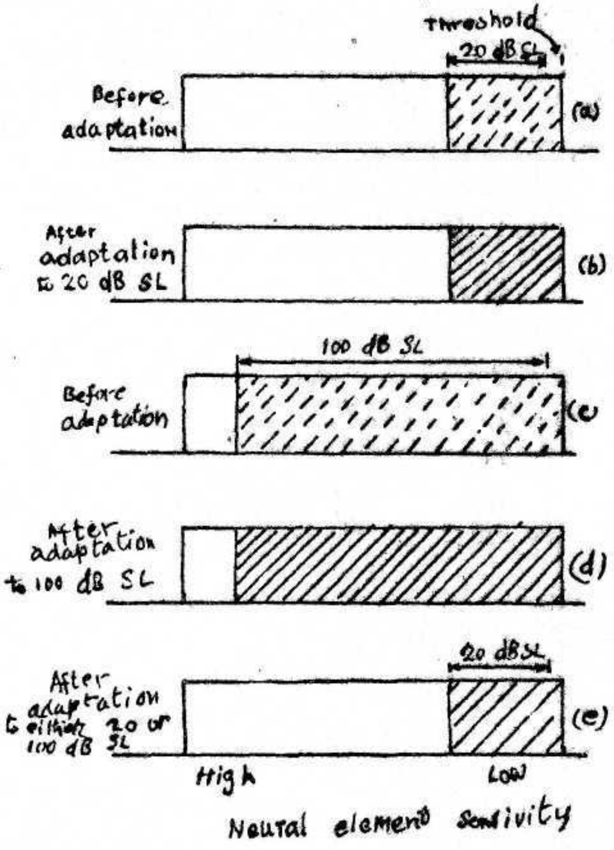

Threshold
20 dB SL
Before adaptation
(a)
After adaptation to 20 dB SL
(b)
100 dB SL
Before adaptation
(c)
After adaptation to 100 dB SL
(d)
20 dB SL
After adaptation to either 20 or 100 dB SL
(e)
High
Low
Neural element sensitivity

Fig. 1

units may become less sensitive and cease to respond to the 20 dB SL stimulus. (5) Another important assumption is that the distribution of the neural elements which cease to respond is lndependent of the element's initial sensitivity. Thus the density of active elelments is decreased and this condition is represented in Fig. 1b According to the initial assumption, the loudness of this stimulus will decrease. (6) Now consider the presentation of a 100 dB SL stimulus (Fig.1c). A greater number of units are now activated, including the units which responded to the 20 dB SL stimulus as well as a number of addition units which have lower sensitivities. (7) If this stimules is contined indefinitely a situation will occur similar to that described in steps 4 and 5. The result of this is shown in Fig. 1d (8) It is important to note as additional assumption; nearly that the number of units which cease responding as the result of prolonged stimulation is a constant proportion of the total number initially activated. (9) If now, following a prolonger exposure to a 100 dB SL stimulus, a 20 dB SL, stimulus is presented, the same number of units will be available as could hava been the case had the exposure been to a stimulus of 20 dB SL. Thus, the change in loudness in a 20 dB SL, stimulus will be the same whether the adapting stimulus is 20 or 100 dB. This situation is illustratad in Fig. 1e

The assumption mentioned in step 5 is an interesting one. It implies that once the intensity of the stimulus is great enough to excite a particular element, it is immaterial, in terms of the length of time the element will continus to fire, how much greater the intensity becomes. If this is so, then the crucial factor would seem to be simply the length of time it has been firing. Under these conditions it is reasonable to suppose that there is a recovery process going on simultaneously with the adapting process. That is, certain elements will cease firing because of prolonged activity, while others may regain their intial sensitivity and begin activity again.

It should be noted that the formulation just advanced need not be changed in order to account for the effect of intensity upon threshold shifts brought about by prior stimulation. It is only necessary to point out that the threshold is dependent in a different way upon the sensitivity of the neural elements. The decreased sensitivity brought about by exposure simply requires that a more intense stimulus be presented in order that the fixed number of fiders required for threshold be activated.

If the material illustrated in Fig. 1 is extended it is possible to account for the symmetrical spread of adaptation from the frequency of the adapting stimulus to neighboring frequencies. It was proponed in the previeus paragraph that loudness adaptation was a result of readering nonfunctional a certain proportion of neural elements which initially responded to the stimulus. (1) The next step is to assume that the population of neural elements considered in Fig. 1 may perhaps beat to thought of as constituting a subpopulation located at a particular point on the basilar memberans. If this subpopulation is not on the basilar membrane, then it could be located at some place in the peripheral auditory system which is functionally connected point for point to the basilar membrane. (2) Thus, as a function of continued stimulation neural elements are locally rendered nonfunctional. Furtherefore, it is likely that this effect is to be found in the region of the basilar membrane in which maximum displacement occurs in response to a particular frequency. (3) consider now the situation in which a teat stimulus is introduced whose frequency is different from that of the adapting stimulus. It would be expected that if the elements responding to the test stimulus were in part those which had responded to the adapting stimulus, the test stimulus would exhibit a loudness decrement in proportion to the degree of overlap between the two neural population. (4) for tonal stimuil the displacemant and, therefore, probably the excitation of neural elements along the basilar membrane are not uniform. Thus, the distribution of excitation must be considered in determining the amount of funotional overlap. (5) As the frequencies of the test and adapting stimuli are separated, the area of overlap between neural populations decreases and consequently the amount of adaptation decrease. It should be noted that as long as the distribution of exaitation along the basilar membrane is simllar for each stimulus, the area of overlap will be the same regardless of whether the test frequency is above or below the adapting frequency. Thus a symmetrical spread of adaptation will occur.

Using listeners with normal hearing, it can only be determined that the locus of loudness adaptation is peripheral rather than central. The use of listeners with various types of peripheral auditory pathology should serve to better define the structures involved.

However, invsatigators who have studied this problem find marked loudness adaptation in patients with either cochlear involvement (for instence, see Hood, 1950) or disorders of the eighth nerve (of, Jerger, 1960, for example). From the standpoint of the hypothosis being advanced here, the exact loudness is immaterial; it could be either the hair cells or the eighth nerve or both, provided the provisions of step 1 are fulfilled,

Tho question of the time course of adaptation and reeovery is extremely important in selection of the responsible specific physiological mechanism. If the time course is extremely rapid, as seems to be the case for short-term fatigue, them it is tempting to postulate a mechanism related to neural refractory periods. If, on the other hand, the phenomenon reflects slow changes, as does temporary threshold shift following rather internse stimuli, then some type of mechanism related to large scale metabolic activity would appear a possibility.

In the case of loudness adaptation and recovery,the changes, although perhaps more rapid than those in long-term fatigue, still seem much too long to put in the same class as short-term fatigue. The most likely mechanism would seem to involve the depletion and resupply of matabolic reserves associated with neutral setivity in the peripheral portion of the auditory system.

Quite obviously many of the concepts proposed represent a gross oversimplification of loudness adaptation. It may be, however, that the very simplicity of the notions allows predictions, which may be tested experimentally, to be made more easily. At best, these hypotheses are only a framework on which to build. It seems possible that some building may to done with relatively little effort. For instance, pitch shifts under conditions of adaptation, masking or cochlear pathology may perhaps be incorporated with no additional assumptions.

..There are strong indications from many pieces of evidence that leudness adaptation does not increase indefinitely with time, but that it reaches an asymptotic or steady-state value after a certain period. The question is—what period? If data gathered with simultaneous dichotic balances are considered the answer seems to be 4 to 7 min. On the other hand, data from intermittency studies and those gathered with the moving phentom method indicate that 30 to 90 sec is a more reasomable estimate. Clearly, this question amomg others will not be resolved until more adequate procedures are available.

Actually, things are not so bad if all that is desired is to make statements about the relative time course of adaptation as influenced by varioua experimental variables. For instance, invastigators are nearly unanimous in their finding that the time taken to reach asymptote increases as the intensity of the adapting stimulus increases. The effect of frequency is less well documented. The evidence that does exist seems to indicate no special effect other than that arising from the intensity of the adapting stimulus. That is, low frequencies reach asymptote more quickly than high frequency, but apparently only because the time to asymptote is related to the loudness of the adapting stimulus and for a constant SPL low frequencies tend to be less loud than higher frequencies Although mush more work needs to be done with intermittent stimuli, they seem to follow the same general trends as do other stimuli. The general rule is_____the greater the asymptotic level of adaptation, the greater is the time it takes adaptation to reach asymptote.

Remarkably little is known about recovery from loadness adaptation. Comparatively few studies have been done and most of those were carried out with methods that severely impair the value of the results. The studies using more adequate methods have simply failed to vary systematically the intresting experimental variables. Adequacy of methodology is again a battleneck. Probably the method of intensive localization is the best of the current group. Although restimulation of the recovery ear is minimized by the use of very short test stimuli, simultaneous dichotic balances are used with their attendant difficulties. There is a pressing need for further research designed to answer such questions as these. (a) How long does it take the ear to recover from loudness adaptation?

(b) Does this time vary as a funtion of the characteristics of the adapting stimulus such as duration, intensity, or frequency? (c) Are the effects of those variables above and beyond simply the amount of adaptation they produce before recovery is allowed to begin?

The absolute amount of adaptation is likely to be influeneed by such things as the amount of adaptation which has taken place in the comparison ear to a greater degree than is the time course of adaptation. For this reason much of the data in this area should be regarded with caution. for example, traditional procedurse suggest a maximum amount of loudness adaptation to be of the order of 90 dB. Wright would suggest on the basis of his data that 50 to 60 dB is a more reasonal estimate. Clearly, this apparent discrepancy needs to be resolved.

A large group of studies have been carried out which investigated the influence of a number of experimental variables upon the amount of adaptation. A comparison of the relative adaptation obtained under these conditions is informative and probably not too far from correct, provided that a linear transformation exists between current data and data which will ventually be obtained with superior methods.

when the amount of adaptation was mesaured at an intensity less than that of the adapting stimulus, it was found that adaptation did not depend upon the intensity at which the ear was adapted, but only upon the intensity at which adaptation was measured. This is an extremely important finding although it was confirmed by a second investigator, it should be noted that both studies used the same methodology. Because of its importance, it would seem desirable to look for the same effect using a different experimental procedure. In addition, this phenomenon, together with its hypothesized neural basis, suggests that if the intensity of the adapting stimulus is less than that of the test stimulus, appreciably less adaptation should be observed than if test and adapting stimuli were of the same intensity. This hypothesis has not yet been tested.

Ward (1973) distinguishes the phenomena commonly included under adaptation in two different ways: Whether they are observed during or after exposure to the acoustic stimulus (concomitant or residual respectively) and whether they require one ear (Menaural) or two (Binsural) for their maeasurement. Example for these four categories—concomitant monaural, comcomitant binaural, residual monaural and residual binaural—-are; tone decay, perstimulatory adaptation, TTS and loudness reduction (measured by ABLB test) respectively.

Many techniques (see small, 1963) have been developed for measuing adaptation in its develepmeat, asymptotic stats and recovery. simultaneous Dichotic Loudness Balance (SDLB) technique, since it entails no interruotion of the adaptying stimulus is the best yet devised for measuring the development of adaptation (Elliott and Fraser, 1970). Asymptotic localisation and the moving phantom methods give information about maximum amount of adaptation. The methode of intensive and phase localization are appropriate for measuring

recovery from adaptation.

The SDLB technique is the one that has been more frequently used for measuring all of the aspects of adaptation. Several variation of this technique have been developed. Regardless of specific method of presentation, the SDLB technique has serious drawbacks (Elliott and Fraser, 1970);

1. Adaptation of the comparison ear through cross-over of the adapting stimulus (adapting stimulus > 70 dB SL may couse adaptation in the comparison ear). Procedurally, little can be done to handle each cross-over phenomena if the relation between adaptation and intensity of the asapting stimulus is linear as has been suggested by Hood, Carterette and Jerger then the only problem cross-over presents is that of underestimating the extant of adaptation at the higher intensity levels. However, if the relation is in any way nonliner, the true datum is completly obscured.

2. Maintaining a continuous tone in the comparsion ear during a loudness match can be detrimental.

3. The subjects may maka use of both loudness and localization cues While making loudness judgemeats.

Ward (1973) has explanined 'perstimulatory adaptatio' in the following manner:

> ...Perstimulatory adaptation therefore appearing only when both ears are stimulated simultaneously, is a complex phenomena involving central interaction of the auditory pathway including, perhaps, efferent action of the non exposed ear. The maximum effect, always reached in 5 min or less, seems to be obtained under the following conditions:
>
> 1. When the control ear is given a pulsed tone instead of a continuous one (this keeps the effect from diminishing during the process of testing for it) (Wright, 1960).

2. When the stimulus is a pure tone instead of a noise; apparently irregularity helps minimize the growth of perstimulatory adaptation (Carterette, 1956).

3. When the adapting stimulus is continuous, although an intermittent tene or noise shows some adaptation, it is always less than for a steady adaptation (Sergeant & Harris, 1963).

4. When the instruction emphasize the median plane balance rather than 'equal loudness' (Stokinger & Studebaker, 1968).

5. When the comparison stimulus has the same frequency as the fatiguer, although there is considerable spread of effect to both higher and lower frequecies (Thwing, 1955).....

6. When the test subjects ars adults; Karja (1968) found that the average perstimulatory adaptation. in 7-15 year-old childrea was not significantly different from zero.

Just what processes underlie this fascinating phonomenon are still unknown, but no doubt the same once are involved in;

1. the shifts in lateralizing power of tones after a subject wears a hearing aid in only one ear (Elfner and Carlson, 1965);

2. the changes with time of contralateral remote masking (Ward, 1967); and

3. the decreased TTS observed after binaural exposure relative to monaural exposure, over and beyond any effects attributable to middle-ear muscle action (Ward, 1965).

Perstimulatory adaptation seems to have little clinical usefullness so far, at least nothing seems to correlate well with individual differences in degree of adaptation (for example, Palva, 1955). Although Tanner (1955) observed a negative correlation between perstimulatory adaptation and ordinary TTS, I have been unable to duplicate this finding (Ward, 1968). Karja (1968) found no change in old age. For the moment, then, perstimulatory adaptation remains a provoking enigma.

Finally, Ward (1973) concluded that, "perstimulatory adaptation reflects a changes in the 'potency' of stimuli in regard to lateralization following monaural stimulation it is demonstable only by binanural presentation of test signals, and therefore involves complex judgmental processes relatively high up the auditory chain (though the possible efferent action of monaural stimulation on the periphery of the contralateral auditory system cannot be excluded)",

The studies regarding the effects of duration intensity and frequence of the adapting stimulus on the amount of adaptation and also on the recovery time are exhaustively reviewed by Elliott and Fraser (1970);

> .. .Growth. Putting aside the inherent methodological problems we can proceed to the data that have been gathered on the phenomenon or adaptation. In general, its course of developmont is one of negative acceleration, with the greatest rate of adaptation occurring during the first one or to minutes (Fig. 2), and the asymptotic level being reached anywhere from three to sevan minutes after the onset of the adapting stimulus. Most of the recovery from adaptation occurs within one minute, and recovery is complete within two minutes. Additionally, adaptation has a roughly linear relation to the intensity and little or no relation to the frequency of the adapting stimulus.
>
> Although the developmental course of adaptation is well established, the values found at any particular point on that curve vary widely between inveatigtatoras The extent of the discrepancies can be seen in Fig.4 By far the most divergent results are those of Hood (1950) and Palva (1955). Both used a tracking procedure in obtaining the loudness matches, but their attentuation rates differed. Palva used a motor-driven

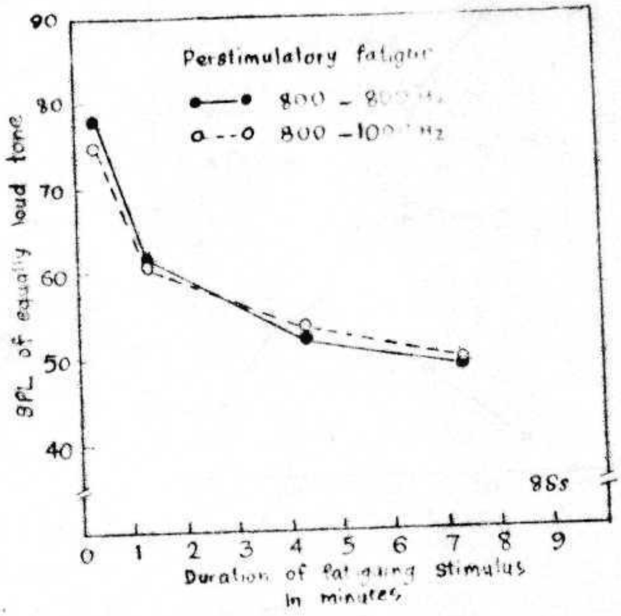

Perstimulatory fatigue
800 - 800 Hz
800 -1000 Hz
SPL of equally loud tone
90
80
70
60
50
40
88s
0
1
2
3
4
5
6
7
8
9
Duration of fatiguing stimulus in minutes

Fig. 2

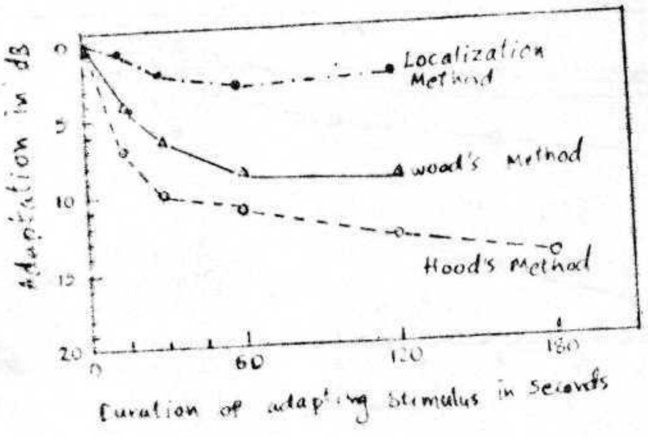

Localization Method
wood's method
Hood's Method
Adaptation in dB
0
5
10
15
20
0
60
120
180
Duration of adapting stimulus in Seconds

Fig 3

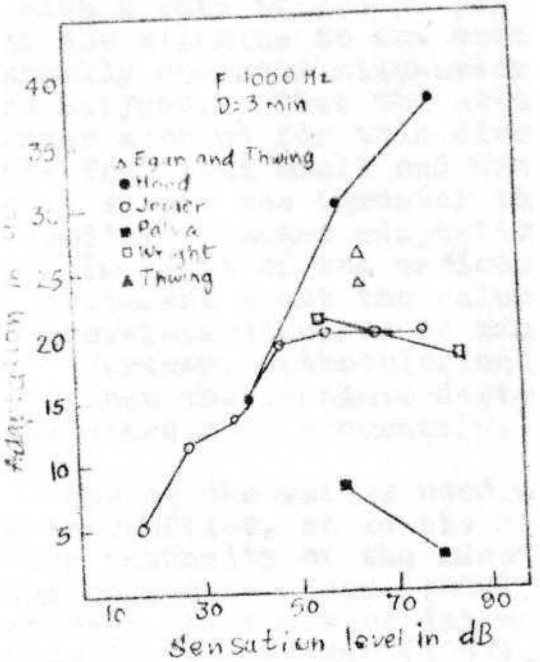

F 1000 Hz
D=3 min
Egan and Thwing
Hood
Jerger
Palva
Wright
Thwing
Adaptation in dB
40
35
30
25
20
15
10
5
10
30
50
70
90
Sensation level in dB

Fig.4

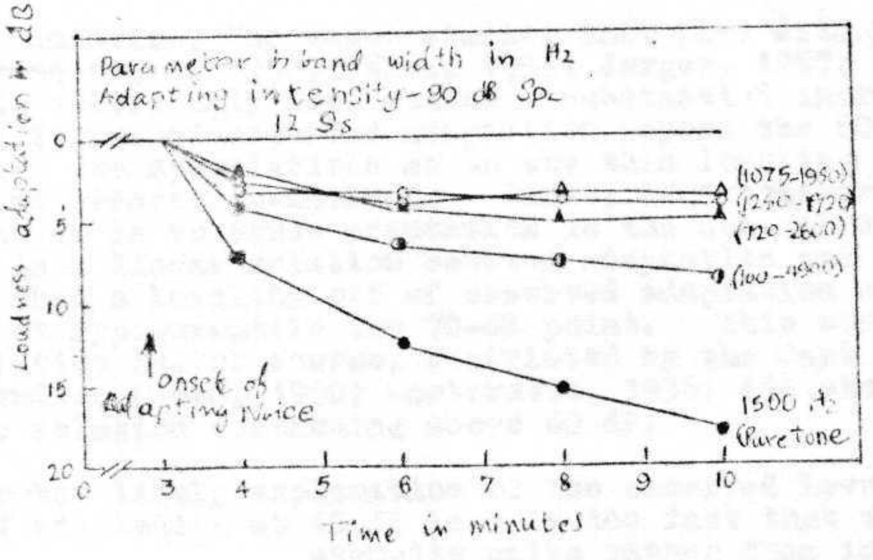

Parameter is band width in Hz
Adapting intensity-90 dB Spl
12 Ss
Loudness adaptation in dB
0
5
10
15
20
(1075-1950)
(1250-1720)
(720-2600)
(100-4900)
1500 Hz
Puretone
onset of
Adapting Noise
0
3
4
5
6
7
8
9
10
Time in minutes

Fig. 5

attenuator with a rate of 2.3 dB per sec for the presentation of the stimulus to the control ear, and Hood used a manually operated attenuator with a rate governed by the subject. That the attenuation rate may in some manner account for this divergence is supported by the fact that small and Minifie (1961) using a rate of 5 dB per sec (greater than Palva's, but less than Hood's) Obtained adaptation of an intermediate value. In light of the various studies, even a general statement about the values for any point along the development curve of adaptation would be misleasing. Further, methodological studies are sorely needed so that the absolute degree of adaptation may be determined more accurately.

Intensity. Just as the values used a describing adaptation are in conflict, so is the relation of adaptation to the lntensity of the adapting stimulus. For a continuous pure tone, Hood (1950) found a roughly linear rolation over the range of intensity values he investigated(Fig: 4), Jorger (1957), too, demonstrated a linear relation, at least from 10 dB to 60 dB SL, but above this level, the function flattens out (Fig:4). Additionally, in those studies that investigated only two intensities (Palva, 1995; Wright, 1960), there is no increase in adaptation as a function of the adapting lntensity.

To summarizem, for those studies that have data points in common (Hood, 1950; Palva, 1955); Jerger, 1957; an-Wright, 1960), only Wood showed a substantial increase in the degree of observed adaptation beyond the 60-dB level. Two speclations as to why this leveling off occurred present themselves. First, if crossover does operate so as to cause adaptation in the control ear and there is a linear relation between adaptation and intensity, then a leveling off of observed adaptation would occur at approximately the 70-dB point. This sort of speculation is, of course, restricted by the fact that twe studies (Hood, 1950; Carterette, 1956) did show a linear relation continuing above 60 dB.

Another likely explanation of the observed leveling off of adaptation at 60 dB lies in the fact that the data are plotted in intensity units rather than in subjective loudness units. Carterette (1956) found a linear relation only when he made just such a transformation. Although a general statement might be that adaptation

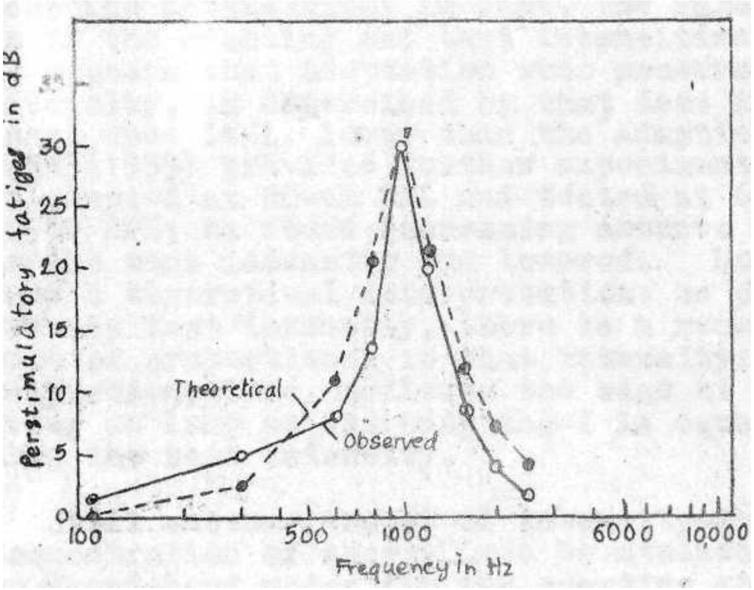

Perstimulatory fatiges in dB
35
30
25
20
15
10
5
0
Theoretical
Observed
100
500
1000
6000
10,000
Frequency in Hz

Fig.6

and the intensity of the adapting stimulius are linearly related, the upper limit or this function remains in doubt, Morw evidence is needes(before much a statement can be made with confidence.

Adaptation can be measured at latensity levels other than that of the adapting stimulus, This aspect has been investigated only by adapting the test ear at one intensity and measuring adaptation at a lower intensity. The opposite procedure has received no attention. The effect of adapting at one intensity and measuring adaptation at a lower intensity was first investigated by Hood (1950), who exposed the ear to a 100 dB SL tons and then measured adaptation at sensation lovels extending from 20 dB through 100 dB. The Adaptation be found was similar to that seen with lower adapting intenasities; in fact, the values were the same as if the adapting and test intensities were identical. It appears that adaptation when measured at any given intensity, it determined by that test intensity—at least when it is lower that the adapting intensity. Egan (1955) provided further experimental support when be adapted at 80-dB SPL and tested at 60-, 70-, and 60-dB SPL; he found decreasing amounts of adaptation as the test intensity was lowered. Hood (1950) offered a theoretical interpretation; ha postulated that for any test intensity, there is a receptor group whose size of proportional to that intensity; the amount of adaptation, then, reflacts the size of the receptor group so long as the adapting I is equal to or greater than the test intensity.

Still another aspect of inteasity-the effect of concentration of energy—can be studied by using narrow- or broad-band noise for the adapting stimulus. Carterette (1956) compared several bands of noise and a 1500-Hz tone using the methods of fixed and variable intensity, with 50-, 70-, aad 90-dB SPL adapting stimuli. The results indicate that adaptation tends to increase as bandwidth increases, at least for the 90-dB SPL intensities (Fig. 5). Apparently as the available energy is apread over a broader frequency range,it adapts a larger receptor group. An exception to this tendency is evideat in Fig:5 ,where it will be noted that pure tone stimulation produces the greatest adaptation, which suggests the development of fatigue.

Interruption Rate. Carterette (1995) measured adaptation to a noise that warn interrupted at rates varying from 1 to 12.4 per sec, with a 50 percent duty cycle, First, he observed that, with total energy equal to that in a continuous adapting noise, the contiouous noise produces more adaptation. Second, as interruption rate increases the degree of adaptation also increases. Carterette suggested that, as interruption rate is incresed, the time for recovery is shortened and, thus, cumulative effects may be produced. However, the period of adaptation is likewise reduced, Apparently recovery processes suffer relatively more from the increase to interruption rate than do the adapting processes; thus there must be either a latency in the onset of the recovery processes or an initial recovery rate lower than the initial adapting rate. Certainly, these findings again emphasize that too little is known of the initial stages of adaptation and recovery.

Frequeacy. Two aspects of the frequence parameter merit discaussione. First, does adaptation vary as a function of the frequency of the adapting stimuls, and second, does adaptation of one frequency spread to neighboring frequencies. Conidering the first aspect, Jerger (1957), found a slight tendency for adaptation to increase as frequency increases from 125 Hz to 1000 Hz, but to remain approximately oonatant for frequencies from 1000 through 6000 Hz confirming evidence is lacking. since most studies have confined themselves to one frequency. Of those studies that used two or more frequencies (Hood, 1950; Falva, 1955), differences in adaptation as a function of the adapting frequency were not reported.

As for the spread of adaptation to neighboring frequencies, there has been only one comprehensive study (Thwing, 1955). Apparently adaptation, at least for 1000 Hz at 80-dB SPL, has its maximum effect at the adapting frequency, with continuously lower degrees of adaptation observed on both sides until at 100 Hz and 2500 Hz, it has completely disappeared (Fig:6). Thwing suggested that adaptation is proportional to the extent to which excitation patterns of the adapting and comparison stimuli overlap. A theoretical curve based on this hypothesic is shown in Fig. 6 ; it is symmetrical just as the data points are. Whether adaptation is always greatest at the adapting frequency, irrespective of frequency and intensity, is not known. The collection or such data would be of value in it a own right, but additionally, would provide an evaluation of Thwing's hypothesis.

Intensity and, to a much lesser extent frequencey both not to determine the temporal course of adoptation and in particular the point at which its asymptotic state is reached. Originally, Hood (1950) reported that adaptation is complete within 3 to 3.5 minutes regardless of the intensity or frequency of the adapting stimulus. However later studies confirmed this finding only for intensities up to 60 dB SL, or frequencies up to 1000 Hz (Jerger, 1957), Above these values, the frequency effect is negligible, and the degree of adaptation observed becomes primarily a function of the intensity of the adapting stimulus. Also at these higher levels as the intensity increases, the point at which the asymptote is reached is further delayed in general, for the higher intensities, the point of maximum adaptation is reached betweeen five and seven minuts (e.g., see Figs. ... 2, 3 and 5).although increses in adaptation are reported beyond this point at a considerable slower rate. For example, Carterette (1956) reported that adaptation was still increasing at seven minutes when the intensity of the adapting stimulus was 90 dB SPL, that the asymptote is not reached in three minutes in most studies except at lower intensities and lower frequecies is most likely attributable the addition of fatigue proceses.

Recovery. Tho chief difficulty in measuring recovery from adaptation is that the commonest technique (SDLB) involes restimulation of the test ear during the racovery process, Also, the First postadaptation balance has been taken at approximately one minute after the adapting stimulus has been terminated. Thus the recovery process ourtailed by measurmant difficulties, is poorly known. Among those investigations who have used the SDLB technique (Kgan, 1955; Thwing, 1995; Wright, 1959), it is generally agreed that recovery is rapid, with far more racovery taking place in the first minte than in any comparable period thereafter. for example, Egan reported first-minute recovery of abot 70 percent. Thwing reported 80 percent, and Wright reported 75 persent. The most interesting aspect of these data is that, regardless of the extent of adaptation at asymptote, a similar proportion of recovery takes place in the firstt minte. Not one of these investigators reported more then 6 or 7 dB adaptation after 60 sec, even though adaptation at asymptote was as high as 30 dB. Further recovery occurs during the second minute and, with the exception of one report (Wright, 1960, Who observed between

> 3 and 8 dB of adaptation at the three-minute point), the evidence sugests that the functional characteristics of the ear are restored by the third minute,
>
> The SDLS technique gives no information about the course of recovery during the first minute, and since this time period includes most of the recovery, other techniques are more appropriate. The method of intensive localization is preferred because restimuletion is minimised. In this method, the intensity necessery for a median-plane localisation is determined by having the subject report if the fused image is to the left, to the right, or in the center while brief stimuli are presented. The intensity necessary for a "center" judgment before adaptation is compared with the intensity necessary after adaptation. since restimulation is brief, certainly the effect of restimulation is minimized, and the course of recovery during the first minute can be ascertained.
>
> Bekesy (1960, pp 357-358) using this method with stimuli of 0.2 sec duration, found that 80 percent of the recovery occure during the first 5 sec; almost complete recovery occurs within 10 sec, Since the initial level of adaptation was low (15 dB), it is not possible to generalize these findings. Once again, we must close the discussion with the comment that more work needs to be done before definitive statements can be made.

Fraser, Petty aad Elliott (1970) and Petty, Fraser and Elliott (1970) have isentifid binaural interaction or lateralization cues as the important determinant in the magnitude of intensive change required to realise equality between adapting and comparison tones. They found that loudness adaptation was essentially absent when binaural interaction was reduced or eliminated. A reduction in binanural interaction was accomplished in their studies by employing a delayed loudness balance or a heteraphonic balance prooedure.

Morgan and Dirks (1973) conducted experiments to measure suprathreshold loudness adaptation at 500 hz useing a heterophonic listening condition is order to reduce binaural interaction. The adapting stimulas was presenated at 70 dB SPL for 7-min, Along (3000 m sec) and a short (300 m sec) comparison stimulus were chosen to delineate the possible influence of the duration of the comparison stimulus itself on the magnitude of the loudness changes measured. No loudness adaptation was observed during those experimental condition. They concluded that there would be no loudness changes in perstimulatory test condition when binaural interaction was reduced. They also noticed an apparent "enhancement" of loudness during the adapting period when a train of short pulses (300 m sec each) was used as the comparision stimulus.

Bray, Dirks and Morgen (1973) have reported an experi--ment in which perstimulatory adaptation was measured under heterophonic condition useing SDLB procedures on normal listeners, The adapting signals were 500 anA 3000 Hz presented at 70 dB SPL for 12-min, the last 5-min of Which involved perstimulatory loudness balances, A tracking technique and the method of constant stimuli were employed. The result indicated that continuous stimulation did not significantly decrease the loudness of tbe adapting signal. Hence, they have concluded that under test oonditions that reduce or eliminate binaural interaction, suprathreshold loundess adaptation does not result for pure tone signals of 500 and 3000 Hz at 70 dB SPL.

In addition to the above studies, there are many studies (Dirks, MOrgan and Bray, 1974; Mirabella, Tauband Teichaner, 1967; stokinger, Cooper and Meissner, 1972; Stokinger, Cooper. Meissner and Jones, 1972; Stokinger and Studebaker, 1968; Wiley, Small and Lilly, 1973) which suggest that the adaptation effect could be considered to be more central in nature. These Investigators offered conclusion in favour of central origin becouse they could not observe appreciable amounts of adaptation when binaural lateraction was eliminated or reduced. However, Weiler and Gross (1973) showed that adaptation could be measured by means of heterophonic monaural procedure (MH) and these monaural effects were not likely to be due solely to central phenomene. They showed that similar ampunts of adaptation were obtained using SDLB and MH techniques for example, using the SDLB technique with two 1000 Ha tones and the reference tone at 60 dB SPL in preadaptation, adaptation and post adaptation coaditions, the average adaptation waa 20.16 dB (Weller, Loob and Allusi, 1972). similarly the MB technique with the adaption tone at 500 Hz (60 dB) and the comparison tone at 10,000 Hz, the average adaptation was 22.3 dB (Wailer and Cross, 1976).

subsequently Weiler, Linz, Mojdehi and Glass (1979) reported that there was no significant correlation between the magnitude of adaptation measured using SDLB and MH techniques. They offered the following interpretations:

1. Perhaps individual variability in being able to match a high versus a low frequency sound, as in the monaural case, varies so widely among individuals that it partially obscures adaptation effects. Or, conversely, perhaps the ability to do binaural loudness matches varies so such that it partially obsoures the adaptation effects.

2. The two measures could well both vary differently for reasons of individual characteristics which then obsoure any common proceses.

However, the fact is that the measures did not vary together—there was no correlation and unless one can find evidence that the techniques point up differences in the ability to do monaural and binaural judgements independently of adaptation effects, then one must ignore the occurrance of similar means which appeared in the two conditions. One would then conclude that the techniques measure different aspects of auditory changes following adaptation.

Weiler, Loeb and Alluisi (1972) tested small's (1963) prediction to replicate Hood's (1950) and Egan's (1950) and Egan's (1955) findings for the case where adapting tone intensity exceeded that of test tone and farther investigated the growth of loudness at various levels with equal intensities of adapting and test tones. They confirmed that predictions inferred from small's model, of significantly lower sdaptation would result when test-tone intensity exceeded adapting-tone intensity. Further they found that adaptation effects with test and adapting tone equal in intensity incresed between 40 and 60 dB remained relatively constant between 60 and 80 dB. When adapting tore intensity exceesded test tone intensity, the amount of adaptation did mot increase, was also confirmed.

Weiler and Hood (1977) developed an improved model for loudness coding during auditory adaptation. They compared the loudness adaptation measured at four base-line intensities and at test values 10 and 20 dB above the base line intensities and found that there was an orderly declins in the amounts of adaptation. The magnitude of the decline in loudness adaptation with the increasing difference between the test values and the base line was shown to agree with earlier theories. A method for closely estimating the change in loudness adaptation is presanted in convenient graphic form and in sigebraic equations.

interestingly, Glass and Weiler (1979) reported that the results obtained in the two techniques (SDLB and MH) differed considerable when adaptation was measured at an intensity higher than the adaptation intensity. General conclusion were "unlike the finding of Weiler and Hood (1977) for binaural simultaneous measurment of loudness balances the present study useing the monaural simultaneous balance technique did not show a significant decline in adaptation when the test intensity was +10 dB above the adaptation intensity. That is, for the 50 dB adapting tone, we would have expected that less adaptation be measured at a test value of 60 dB (+10 dB above adaptation) then when the test value remained at 50 dB".

"Several cahrectorstics of the present study may have contributed to the results. The subjects were older then previouely, although not greatly so. The monaural balance technique has generally been less stable and more difficult then binaural simultaneous balance techniques and frequecies are different. It is also possible as suggested by Weiler and Davis (1975) that the monaural technique meauraes a differeat auditory change due to adaptation than that measurred by simultaneous binaural balances".

Recently, Mahon and Weiler (1980) have reported a further test of a model for loudness coding after adaptation, They have attempted to fit Weiler and Hood's (1977) quantitative model for loudness coding to an additional set ofa SDLB data. The error of predictions for test values 10 dB above adapting intesity for 12 narmal hearing listeners was -2.7 to -4.7 dB an average of -3.5 dB. Since the error of predictlons was so nearly constant (S.D = ± 7.37 dB), the authors have considerad it resonable to attribute the error to the differences in procedural technique. They have concluded that the loudness model does account for a large component of coding in adaptation results.

Davis and Weiler (1978) have reported ear dominance effects in loudness following auditory adaptation. using MH technique, they found the amounts of adaptation for 500 Hz tone in left and right ears. 10 Subjects were tested in the left ear,a10 in the right. Left ear adaptation was 4.20 dB, while right ear adaptation was 12.88 dB (P 0.001), They have recommended that the possibillty of ear differeance in loudness adaptation be taken into account in future studies.

Vyasamurthy (1977) developed a ne technique - objective

Residual Monaural Loudness Adaptation (ORMLA) to verify Small's (1963) predictions with regard to loudness adaptation, General conclusion of the early iavestigation carried out on a faw normal hearing subjects with

methodolgy and other details are given in Appendix-A.

CHAPTER III

METHODOLOGY

subjects

The subjects participating in the majority of the experiments consisted of 32 to 48 normal hearing (20 dB HL ANSI 1969) students belonging to All India Institute of speech and Hearing, Mysore - 6 and to the nearby colleges, ranging in age from 19 to 27 years. Some experiments were carried out on small samples (5 to 10 subjects) of normal hearing subjects and also for some experiments the investigator, (age:39 Yrs) with normal hearing (20 dB HL ANSI 1969), himself was a subject.

The following criteria were used for the selection of subjects:

1. Normal hearing in both ears (20 d8 HL ANSI 1969) for frequencies from 250 Hz to 4 KHz.

2, Narmal tympanograms in both ears.

3. AcouStic reflex thresholds < 95 dB HL (ANSI 1969) for frequencies: 0.5, 1 & 2 KHz.

4. Normal middle ear pressure (± 50 mm Hzo) in both ears.

5. Consistent increase in the magnitude of reflex (as observed through the deflection of the Balance Meter (BM) needle of the eleotro-acoustic impedance bridge Madsen - Z0 73) with increase in intensity of 1000 Hz tone, (i.e., the subjects, who did not show visually

noticeable consisted changes in the deflection of the BM needle with 5 dB increments in intensity of the test tone, were not included in the experiments-- in these subjects, the compliance changes were less and hence, the instrument was not sensitive enough to detect the small changes. To put it more meaningfully, the subjects who failed to show visibly noticesble changes in the deflection of BM needly, with 5 dB increments in the intensity of the test tone, should not be interpreted as the subjects in whom the loudness does not change with increase in intensity of the test tone)

6. No complaints of ear and/or noss and/or threst infection at the time of testing.

Equipment

(All the data were obtained useing electro-acoustic impedance bridges (Madsen ZO 72 and Z 73), Probe tone (220 Hz) of the bridges were calibrated for 85 dB SPL by using Bruel and kjaer (B & K) equipment (Sound Level Meter - 2203;Oetave Fiter Set - 1613; Condenser Microphons - 4132; s c.c. coupler - DB 0138 and Piston Phone - 4220). Buit-in autiometers of the impedance bridges and thw other audiometers (for screening purposes) Were calibrated far frequency and intensity outputs (and also for linearity of the attenuator) using 203 Timer/Counter Eastern Electronics and B a K equipment (artificial ear 4152; sound Level Meter-2203 with Octave Filter act and condenser microphone-4144) respectively. Standard procedures as described in the Manuals of the impedance bridges and the procedures described by Wilber

(1978) were followed. Calibration checks were made at regular intervals. Appendix-C gives Modson-ZO73 impedance bridge's earphone (Telex-1470 with MX 41/AR cushion) outputs at different frequencies and at different intensity dial readings. Excepts from "schod for Impendance measurments" Z0 72 impedance bring are given in Appandix-B to clarify the concept of impedance and the function of the instrument.

Procedure

In general,there were three stages in the experiments carried out in the present study (All the experiments were carried out in a sound trested room with ambient noise levels less than the prescribed levels). The three stages were: (1) Pre-adaptation (2) adaptation and (3) Post-adaptation.

Pre-adaptation stage. The reflex thresholds of the phone ear (Left ear) and the middle ear pressure of the probe ear (right ear) were determined for each subject using the procedures given in the Manual of Madson Z072/Z073 impedance bridge. Next, the air-pressure in the external auditory meatus of the subbject's right ear was adjusted exactly Cmm H2o, irrespective of the middle ear preasure of the subject (all the subjects had the middle ear pressur of ± 50 mm H20). Sensitivity Knob was set at '3' position and compliance oontrol knob was adjustad until the BM needle showed '1' on the BK scale. BM needle reading '1' was used as the reference for all the subjects.

The test tone was presented for 1.5 sec to the left ear at the reflex threshold level and the BN needle deflection produced by the test tone was noted. After an interval of 30 sec, the test tone was presented at the same level and again the BM needle deflection was noted. Just before the presentation of the test tone,each time, the compliance control knob was adjusted (if found necessary) until the BM needle showed '1' position on the BM scale. the above procedure was followed to find the magnitude of reflex (BM needle deflection or BM reading) for the test tone at different intensity levels. At each level of the test tone, at least, three readings were considered. The consistent readings were considered. The presentation of the test tone at different levels (differing by 5 dB steps) was in random order. The inter-stimmlus interval was 30-sec for test tone levels less than 100 dB SBL and 60-sec for the test time levels 100 dB SPL.)

The above pre-adaptation teasting procedure was carried out prior to <u>every</u> adaptation test.

<u>Adaptation stage.</u> Depending on the type of experiment, the adapting stimulus was presented contiauously for a particular period and at a particular intensity. During this period, the probe tone (220 Hz) was turned off, but the position of the probe was <u>not disturbed</u>. The subject was asked to sit quietly without much bodily movements. Vocalization, yawning,

coughing, laughing, swallowing (frequently) and sneeezing were not permitted during the pre-adaptation, adaptation and post-adaptation stages. If any of these motor activities were observed, the testing had to be done again on a different day.

Post-adaptation stage. A few secouds before the termination of the adapting stimulous, the air-pump was adjusted (if found necessary) until the manometer needle showed exactly 0mm H2o. As soon as the adapting period was over, the adapting stimulus was turned off. A rest period of 5 sec was allowed as this period was necessary to set the knobs to the desired positlions (setting the sensitivity knob to the required sensitivity position. adjusting the compliance control knob until the BM needle showed '1' position; changing the mode of presentation of the test tone; adjusting the frequecy and intensity controls in some experiment only). After 5 sec-reat period, the test tone at a particular level depending on the type of experiment was presented for 1.5 sec--the BM needle deflation produced by the test tone was noted down, This reading was labelled as 'post-adapted BM reading'.)

The 'post-adaptad BM reading' was compared with the 'BM readings' produced by the pre-adapted test tone levels. The pre-adapted test tone level, which had produced the same

'BM reading' (mangnitude of reflex) as that of the post adapted test tone was identified. Adaptation (in dB) was the difference between the post-adapted test tone level and the pre-adapted test tone level which produced the same 'BM reading' as that of the post-adapted test tone. This way, loudness adaptation was measured in decibels objectively. Loudness adaptation measured in the above manner has been termed 'Objective Residual Monaural loudness Adaptation' (ORMLA).

Amount of adaptation (Xb) = Intensity of the post-adapted test-tone
- Intensity of the pre-adapted test tone level which produced the same 'BM reading' as that of the post-adapted test-tone.

Computation of the amount of adaptation is illustred through three examples:

Example 1

Preadapted test tone levels in dB SPL	BM reading (reference)	BM reading	Sensitivity position
	1		3
90	1	2.5	3
95		3.5	
100	1		
105	1		
110	1	6.0	3
		6.5	3
115	1	7.5	3

Postadapted test tone level in dB SOL	BM reading (reference)	BM reading Sinsitivity position	
110	1 '	5.0	3

In the above example, pre-adapted test tone level which had produced the same 'BM reading' as that of the post-adapted test tone level happens to be 100 dB SPL

Therefore Xb = 110 - 100 = <u>10 dB</u>

Preadapted tone level SPL test in dB	BM reading reference	BM reading	Sensitivity position
90	1	2.0	3
95	1	3.0	3
100	1	5.0	3
105	1	5.5	3
110	1	6.0	3
115	1	7.0	3

Postadapted test tone level in dB SPL			
110	1	4	3

pre-adapted test tone level of 93 dB SPL, had produced 'BM reading' of 3.0 and the pre-adaptad test tone level of 100 dB SBL had produced the 'BM reading' of '5.0'. It was assumed that the preadapted test tone level of 97.5 dB SPL would have produced 'BM reading' of '4.0'. This assumption (although not desirable from the point of view of very accurate measurments) was following due to the practical problems. This type of assumption was followed whenever 'BM reading' of the postadapted test tone was mid-way between the two 'BM readings' produced by the preadapted test tone levels differing by 5 dB.

Therefore Xb = 110-97.5 = 12.5 dB

Example 3

Preadapted test tone level in dB SPL	BM reading reference	BM reading	Seneitivity position
90	1	2.0	2
95	1	2.5	2
1oo	1	3.0	2
105	1	3.5	2
110	1	4.0	2
115	1	4.5	2

Postadapted test tone level in dB SPL	BM reading refernce	BM reading	Sensitivity position
115	1	2.5	2

therfore Xb = 115-95 = 20 dB

The procedure for finding the recovery time from adaptation was exactly the same as the precedure used for measuring adaptation, but with a little difference. The procedures used in all the three stages—pre-adaptation, adaptation and post-adaptation—-of the experiments were followed for determining the recovery time. After noting down the 'Bm reading' produced by the post-adapted test tone of 1.5 sec, (at an intensity depending on the type of experiment) 55 sec rest period was given to the subject. At the end of 55-sec rest period, the post-adapted test tone was again presented as before-the 'BM reading' was noted domn. Similarly, 'BM readings' produced by the post-adapted test tone at recovery intervals of 2 min, 3 min, 4 min etc., (i.e, until complete recovery was observed) were noted down. In the experiments IX_b and IX_c recovery process was studied for 10 min of post adapted stage.

The 'BM readings' obtained at 1 min, 2 min, 3 min, 4 min, etc., of post adapted stage were compared with the 'BM readings' which were recorded daring the pre-adapted stage to compute adaptation (in dB) at the different recovery pariods.

In addition to the above general procedures of most of the experiments of the present study, two different types of experiments were also carried out. The two different types of experiments ware : Experiments I and Experiment II.

Experiment I

Experiment I was carried out to know whether pare tones of frequencies viz., 0.5, 1 and 2 KHz at equal loudness levels would produce equal magnitude of reflex in normal hearing subjects. Eight subjects (5M + 3F) in the age range of 20 to 23) years were tested. 'BM readings' obtained for the three tones at 120 dB SPL and at 100 dB SPL ware noted.

Experiment II

A control study on 8 normal hearing subjects ranging in age from 20 to 22 years was carried out to ensure that the magnitude of reflex observed at different intensity levels remained the same after 7 min of silent interval. 'BM readings' for 1000 Hz tone at 90, 95, 100, 105, 110, 115 and 120 dB SPL were recorded The procedure as described in preadaptation stage (p^{59}) was followed. After 7-min silent interval, 'BM readings' for 1000 Hz tone at the different levels were recorded using the same procedure. the procedure used in the pre-adaptation stage.

Using the methodology as explained in this chapter, many experiments (III_a, III_b, IV_a, IV_c, IV_c, V_a, V_b, VI_a, VI_b, VII_a, VII_b, VII_c' $VIII_a$, $VIII_b$, $VIII_c$, $VIII_d$, IX_a, IX_b, IX_c , and IX_d) were carried out in the present study, These experiments are discussed the chapter IV.

To check the reliablility of the result, retest data were also obtained

CHAPTER IV

RESULTS AND DISCUSSION

Experiment - I

Results of the experiment - I are presented in Table 1. This experiment was conducted to know whether pure tones of frequencies viz., 0.5, 1 and 2 KHz at equal loudness levels would produce equal magnitude of reflex in normal hearing subjects. 8 subjects (5 M + 3 F) in the age range of 20 to 30 years were tested. The results show that in all the 8 subjects, the magnitude of reflex as indicated by the BM needle deflection for 0.5 and 1 KHz tones at 120 dB SPL is exactly the same; however, for 2 KHz tone, the magnitude of reflex at 120 dB SPL is less than the magnitude of reflex observed at 0.5 and 1 KHz. Additionally, it was observed that the magnitude of reflex increased with the increase in intensity above 120 dB SBL. At 100 dB SPL, the magnitude of reflex is not the same for 0.5, 1 and 2 KHz tones. This is quite reasonable as we know (through equal loudness contours) that, at 100 dB SPL, the above mentioned tones are not heard equally loud.

Thus, the results of the experiment - I clearly shawed that the magnitude of reflex does indicate loudness perceived by the normal hearing subjects, for pure tones viz., 500 and 1000 Hz.

The above findings and the findings of other investigators, supporting the relationship between loudness and acoustic reflex, were used as the basis for the experiments carried out in the present study.

Experiment-II

Table 2 shows the 'BM readings at different intensity levels of 1000 Hz tone, obtained before and after 7-min 'silent interval'. This study was conducted as a control study. It is clear from the table 2 that the 'BM readings' prior to the 'silent interval' and after the 'silent intensity' are almost the same. A high correlation (r = 0,99) between the two readings at 110 dB SPL of 1 KHz tone was observed.

The above result shows that the new techniqe (ORMLA) can be reliably used for adaptation measurments.

Experiment IIIa

Table 3a shows adaptation values (in dB) with Mean and S.D., for simple adaptation (adaptation measured at the baseline condition), at four durations of exposure for 2 KHz tone at 110 dB SPL. Thirty-four subjects (16M + 18F) ranging in age from 19 to 26 Yrs (Mean age = 20.9) showed the mean adaptation (d8) values of 5.22, 7.98, 10.59 and 9.56 to 2 KHz adapting tone at 110 dB SPL for exposure duration of 3,5,7 and 9-min respectively. Asymptotic state reached by 7-min in most of the subjects.

TABLE 1

'BM readings' obtained in 8 subjects

Subjects	BM sensitivity position	500 Hz		1000 Hz		2000 Hz	
		at 120 dB SPL	at 100 dB SPL	at 120 dB SPL	at 100 dB SPL	at 120 dB SPL	at 100 dB SPL
1	2	4.0	1.5	4.5	2.0	3.0	1.5
2	2	5.5	2.0	5.5	3.5	4.0	2.5
3	2	5.0	1.5	5.0	3.0	4.0	-
4	3	8.5	2.0	8.0	4.0	7.0	2.5
5	3	6.0	1.5	6.5	3.0	5.0	-
6	2	4.5	1.5	4.5	2.5	2.0	-
7	2	5.0	1.5	5.0	2.5	3.0	-
8	3	6.0	2.0	6.0	3.5	4.5	1.5

TABLE 2

'BM readings' obtained in 8 subjects for 1 KHz tone at different intensity levels in dB SPL

Subjects	90	95	100	105	110	115	120
1	3.O(3.O)	4.5(4.O)	5.O(5.O)	6.O(6.5)	7.9(8.O)	8.5(9.0)	10.0(9.5)
2	2.O(2.O)	3.O(3.O)	3.5(9.5)	4.d(4.O)	4.5(4.5)	5.O(5.O)	3.5(9.5)
3	2.0(2.O)	3.O(3.O)	4.5(4.O)	5.5(5.O)	7.O(7.5)	9.O(8.5)	10.0(9.5)
4	3.O(3.0)	4.O(4.O)	5.5(5.O)	7.O(7.5)	9.O(9.0)	10.0(10.0)	-
5	2.O(2.O)	3.5(3.5)	5.O(5.O)	5.5(5.5)	6.O(6.O)	6.5(6.5)	7.0(7.O)
6	-	2.0(1.5)	5.0(5.5)	7.0(7.0)	8.0(8.0)	9.0(9.0)	10.0(10.0)
7.	1.5(1.5)	2.5(2.5)	3.O(3.0)	4.O(4.O)	5.O(5.O)	6.0(6.0)	7.5(8.o)
8.	2.0(2.O)	3.O(3.0)	4.O (4.O)	5.O (5.0)	5.5(5.5)	6.5(7.0)	7.5(8.0)

Figure in parenthesis indicate 'BM readings' after 7- min silent interval.

TABLE 3a

Anditory adaptation values (in decibels) with Mean and S.D.,for simple adaptation at four durations of exposure for 2 KHz tone at 110dB

Subjects	Sex	Age	3-Min	5-Min	7- Min	9-Min
1	M	22	5(5)	10	10	10
2	M	22	5	10	10	10
3	M	20	7.5	5	10	10
4	M	21	0	10	10	7.5
5	F	21	2.5(2.5)	5	5	10
6	M	20	7.5	10	10	7.5
7	M	21	5(5)	5	10	7.5
8	F	20	7.5(5)	5	12.5	10
9	M	21	2.5	5	10	15
10	F F	21	5(2.5)	12.5	15	15
11	F	21	5	12.5	15	15
12	F	20	7.5(5)	10	10	10
13	F	22	5(5)	15	15	15
14	M	19	5	5	10	12.5
15	F	20	5	5	10	10
16	M	26	0(2.5)	0	10	10
17	M	21	0	0	7.5	10
18	F	20	5	5	10	15
19	F	21	10(10)	15	15	15

contd.

-2-

TABLE 3a
continued

Subjects	Sex	Age	3-Min	5-Min	7-Min	9-Min
20	M	21	10	12.5	12.5	12.5
21	M	22	0	12.5	10	15
22	M	20	5(5)	5	5	5
23	F	21	10(10)	7.5	10	7.5
24	M	20	5	5	10	10
25	F	19	15	15	17.5	17.5
26	F	21	2.5	10	10	10
27	M	21	0	5	10	10
28	F	19	7.5(10)	10	12.5	15
29	F	20	5	5	7.5	5
30	F	21	0	5	10	7.5
31	M	21	7.5	10	12.5	15
32	F	21	10	10	7.5	10
33	F	22	2.5	7.5	10	10
34	F	24	7.5	7.5	10	10

mean= mean= mean= mean= mean=9.56
20.9 5.22 7.98 10.59

S.D = S.D = S.D = S.D.= 3.44
3.5 3.87 2.64

Figure in parenthesis indicate values.

The difference as evaluated with the Wilcoxon - T, between the adaptation values obtained at 3 and 5-min of exposure, was statistically significant (T=-18, N=22, P < 0.01).

The difference, as evaluated with the Wilcoxon -T, between the adaptation values obtained at 5 and 7-minn of exposure, was statisatically signifcant (T=-12, N=23, P< 0.01).

The differance, as evaluated with the Wilcoxon - T, between the adaptation values obtained at 7 and 9-min of exposure, was not significant (T=+60, N=16, P > 0.05).

Thus the Null Hypothesis - 1 (Duration of exposure has no significant effect on the amount of adaptation) is accepted when the duration of expoaure is 7 min. The Null Hypothesis is rejected when the duration of exposure is < 7min.

Experiment IIIb

Adaptation values (with Mean) for 0.5, 1 and 2 KHz tones at 110 dB SPL adapted for 3, 5, 7 and 9-min, obtained on a single subject (the investigator - 6 trials) are given in Table 3b.

TABLE 3B

Adaptation values (with Mean) for 0.5, 1 & 2 KBz tones at 110 dB SPL, adapted for 3,5,7 & 9-min

Frequency	Duration of exposure = 3 min						Mean
	Number of trials						
	1	2	3	4	5	6	
500 Hz	5	0	7.5	7.5	5	2.5	4.58
1000 Hz	7.5	10	7.5	5	5	5	6.66
2000 Hz	5	5	7.5	7.5	5	5	5.83

frequency	Duration of exposure = 5 min						Mean
	Number of Trials						
	1	2	3	4	5		
500 Hz	5	5	7.5	7.5	5		5.83
1000 Hz	10	10	10	10	7.5		9.58
2000 Hz	7.5	7.5	10	7.5	7.5	7.5	7.92

Frequency	Duration of exposure = *7* min						Mean
	Numberoftrials						
	1	*2*	3	4	5	6	
500 Hz	10	10	7.5	10	7.5	10	9.16
1000 Hz	12.5	10	12.5	10	12.5	10	9 .16
2000 Hz	15	12.5	12.5	15	15	15	14 .16

Frequency	Duration of exposure = 9-min						K#am
	Number of Trials						
	1	2		4	5	6	
500 Hz	10	10	7.5	10	10	10	9 .58
1000 HZ	12.5	12.5	12.5	10	12.5	10	10 .0
2000 Hz	12.5	15	12.5	15	15	*12.5*	14 .58

TABLE 4a

Adaptation values (in dB) with Mean & S.d. for adapting frequencies of 500 and 1000 Hz at 125 dB SPL for 3-min exposure

Subjects	sex		Adaptation at 500 Hz	Adaptation at 1000 Hz
1	F	19	5	15
2	F	22	15	20
3	M	22	20	25
4	M	22	10	20
5	M	21	10	25
6	F	20	15	20
7	F	20	5	10
8	F	20	15	20
9	F	20	7.5	15
10	F	20	10	25
11	F	19	20	25
12	F	19	20	25
13	F	22	15	25
14	F	21	15	25
15	F	22	5	15
16	F	20	5	10
17	M	22	5	10
18	F	20	5	12.5
19	F	19	5	10
20	F	20	10	15
21	F	22	10	17.5
22	F	21	20	25
23	F	21	20	22.5
24	F	20	10	15
25	F	20	7.5	10
26	M	20	15	20
27	M	22	10	15
28	M	23	15	17.5
29	M	21	5	10
30	M	21	5	7.5
31	M	25	5	10
		Mean=20.3		Mean=19.42

The results show that at all the three frequencies (.5, 1 and 2 KHz) asymptote has reached by 7-min of exposure.

Experiment IVa

Table 4 a reveals adaptation values (in dB) with Mean and S.D.for adapting frequencies of 500 and 1000 Hz at 125 dB SPL for 3-min exposure.

Thirty one subjects (12 M + 19 F) ranging in age from 19 to 25 Yrs (Mean age = 20.3) showed mean adaptation values of 11.61 (S.D = 5.45) and 19.42 (S.D = 6.13) for adapting fraquencies viz., 0.5 and 1 KBz at 120 dB SPL for 3-min exposure, respectively.

The difference, as evaluated with the Wilcoxon - T, between the adaptation values obtained for 500 Hz and 1000 Hz adapting tones, was found to be statistically significant (Z = -4.86, N = 31, P < 0.00003).

Experiment IVb

The results of the experiment IVb are presented in Table 4b. Mean adaptation values obtained for 33 subjects (16 M + 17 F) in the age range 19 to 27 Yrs - (Mean age = 20.75) for 1 KHz and 2 KHz adapting tones, adapted for 7-min at 110 dB SPL are: 7.65 (S.D. = 3.34) and 11.44 (S.D = 3.67) respectively.

TABLE 4B

Adaptation values (in dB) with Mean and S.D., for 1000 and 2000 Hz adapting frequencies at 110 dB SPL for 7-min exposure

Subject	Sex	Age	Adaptation at 1KHz	Adaptation at 2 KHz
1	F	19	5	10
2	F	20	15(12.5)	20
3	F	19	10	15
4	F	19	10	15
5	M	27	10	12.5
6	F	19	2.5	5
7	M	19	12.5	15
8	M	20	2.5(5)	10
9	F	21	5(5)	10
10	F	19	10(7.5)	15
11	F	19	10	17.5
12	M	21	5	10
13	M	23	10(7.5)	12.5
14	M	24	7.5(10)	12.5
15	F	19	10	12.5
16	F	21	7.5(10)	12.5
17	M	23	2.5	10
18	M	24	0(0)	7.5
19	M	22	10	12.5
20	F	20	5(5)	12.5
21	F	19	12.5	15
22	F	20	15	20
23	M	20	10	10
24	M	21	10	10
25	M	20	5(5)	5
26	M	20	5	9
27	F	21	5	10
28	M	21	12.5	15
29	F	21	7.5(10)	12.5
30	F	21	5	10
31	M	19	5	12.5
32	M	21	5	7.5
33	F	22	5	10
		Mean=20.75	Mean=7.65	Mean=11.44
			S.D=3.34	S.D=3.67

Figure in parenthesis indicate re-test values.

the non-parametric Friedman X^2 test (Siegel, 1956) was used to make comparison of the results. The difference between the adaptation values of the two frequencies, was found to be statistically significant.

$X^2 = 25.45$; df = 1; P 0.001)

From the results of the experiments—IVa and IVb, the Null Hypothesis-2 (Frequency of the adapting stimulus has no significant effect on the amount of adaptation can be

Experiment-IVc

Table 4c gives the results of the experiment IVc. Mean adaptation values (6 trials on the same subject—the investigator) for the adapting frequencies viz., 0.5 KHz and 1 KHz at 125 dB SPL (i.e,, at equal magnitude of reflex--implying that the adapting0 tones are presented at equal loudness levels for 7-min) are: 20.83 (S.D = 1.18) and 22.20 (S.D = 1.95) respectively.

The results show that the 'frequency effects on the amount of adaptation is negligible when the adapting tones at different frequencies are presented at equal loudness levels for 7-min. Thus it may be inferred that there may not be any 'frequency effect' in adaptation provided, the adapting tones at different frequencies are presented at 'equal-loudness' levels.

Table 4c

Adaptation values (in dB) with. Mean and S.D., for adapting frequencies Viz., 500 and 1000 Hz- at 125 dB SPL (i.e., at equal magnitude of reflex) for 7- min exposure.

Number of Trials	Adaptation. at 500 Hz	Adaptetion at 1000 Hz	Mean & S.D for 500 Hz	Mean & S.D. for 1000 Hz
1	20	20	Mean = 20.83	Mean = 22.2
2	20	22.5		
3	22.5	20	S.D.= 1.18	S.D.= 1.95
4	22.5	22.5		
5	20			
6	20	20		
7	20	22.5		
8	20	25		

TABLE 5a

Adaptation values (in dB) with Mean and S.D. obtained at 1000 and *2000* Hz test tones after adapting the ear using 1 KHz tone at 110 dB SPL for 3-min exposure

Subjects	Sex	Age	Adaptation measured at 1000 Hz	Adaptation measured at 2000 Hz
1	M	20	5	2.5 (2.5)
2	M	22	0	2.5
3	M	20	12.5(10)	7.5 (5)
4	M	20	5	5
5	F	19	2.5 (5)	0
6	F	20	7.5	10(7.5)
7	F	19	7.5(10)	5
8	F	20	2.5	0
9	F	20	7.5(5)	0(0)
10	F	20	5	0
11	M	21	5	0(0)
12	M	21	5(5)	0
13	M	19	5	10(5)
14	M	20	5	7.5
15	F	21	2.5(2.5)	0
16	M	21	5 (2.5)	2.5(5)
17	F	21	0	2.5
18	F	22	10	5(0)
19	M	22	5	0
20	F	22	5	0(5)
21	M	20	5 (9)	2.5
22	F	22	5	5
23	F	22	5	0(0)
24	F	22	9 (5)	0
25	F	21	5	5 (2.5)
26	f	22	5 (5)	5
27	M	21	2.5	0
28	M	20	0	0
29	M	19	10	10
30	M	19	2.5	5
31	M	22	5	2.5
32	M	20	5	0
33	M	19	0	0
34	M	25	7.5	5
		Mean=20.1	Mean=4.85 S.D=3.25	Mean=2.94 S.D=3.16

Experiment Va

Table 5a shows the results of the experiment Vz. 1 KHz at 110 dB SPL for 3-min, was used as the adapting stimulus. Adaptation was measured separately useing test tones viz., 1 KHz and 2 KHz at 110 dB SPL. The mean adaptation values obtained are: 4.85 (S.D = 3.25) at 1 KHz and 2.94 (S.D = 3.16) at 2 KHz. Thirty-four subjects (19 M + 15 F) in the age range of 19 to 25 Yrs were used in this experiment,

The results show that adaptation spreads to the neighbouring frequency. This result can be viewed as not out of line with the results reported by other investigators.

The difference, as evaluated with the Wilcoxon - T, between the adaptation values obtained at 1 and 2 KHz test tones, was found to be significants ($Z = -3.38$; $N = 28$; $P < 0.0003$).

Since the results show that there is significant differeace in the amounts of adaptation measured at different test tones, the Null Hypothesis—3 (Frequency of the test tone has no significant effect on the amount of adaptation) can be rejected.

Experiment Vb

Table 5b reveals the spread of adaptation to 500 and 2000 Hz regions. 1 Khz at 125 dB SPL for 7-min was used as

Table 5b

Adaptation values (in dB) with Mean and S.D.,
obtained at test frequencies viz., 5,1and
2 KHz after adapting the ear using 1 KHz tone
at 125 dB SPL for 7-min exposure

Number of trials	Adaptation value (1 KHz-125-7 min) measured at 0.5Hz (125)	Adaptation value (1 KHz-125- 7 min) measured at 1KHz (125)	Adaptation value(1KHz 125-7 min) measured at 2 KHz (125)
1	15	22.5	20
2	15	20.0	20
3	12.5	22.5	22.5
4	15	20.0	17.5
5	15	20.0	17.5
6	15	20.0	20
	Mean. = 14.56	Mean = 20.83	Mean = 19.6
	. S.D. = 0.93	S.D. = 1.18	S.D. = 1.71

Code : Adapting frequency - adapting intensity - duration of
exposure of the adapting stimulus.

the adapting stimulus Adaptation was measured separately at test tones viz., 0.5, 1 and 2 KHz (Adaptation was measured at 125 dB SPL for all the test tones). Mean adaptation values (6 trials on the same subject - the investigator) at 1 KHz, 0.5 KHz and 2 KHz are : 20.83 (S.D = 1.18); 14.58 (S.D = 0.93) and 19.60 (S.D = 1.71) reapectively.

The above experiments (Va and Vb) show that adaptation is maximum at the adapting frequency and that there is a spread of adaptation to the neighbouring frequencies. These findings are in agreement with the results reported in the literature:

Experiment VIa

Adaptation values (in dB) with Mean and S.D., for simple adaptatioa at three intensities of 1000 Hz tone for 3-min exposure, are presented in Table 6a. Mean adaptation values (base-line condition) for 1 KHz tone presented continously for 3-min at intensities viz., 100, 110 and 120 dB SPL are: 1.91 (S.D = 2.23), 8.89 (S.D = 3.89) and 18.16 (S.D = 4.81) respectively. thirty-four subjects (M = 13, F = 21) is the age range 19 to 26 Yrs (Mean age = 21.6) were tested.

Friedman test indicated that—the overall increase between 100 dB SPL and 120 dB SPL was significant (X^2 = 63.18; df = 2, $P < 0.001$). The incresas between 100 dB SPl and 110 dB SPL was significant (X^2 = 24.7; df = 1, P 0.001).

TABLE 6a

Adaptation values (in d*B)* with Mean and S.D., for simple adaptation at three intensities of 1000 Hz tone for 3-min exposure

subjects	sex	Age	Adaptation score 1 KHz 100 dB SPL	Adaptation score 1 KHz 110 dB SPL	Adaptation score 1 KHs 120 dB SPL
1	F	19	2.5	10	
2	F	20	0(0)	7.5	15
3	F	20	0	10	17.5
4	F	21	5(5)	10	20
5	M	19	0	10	20
6	*M*	21	5	15	25
7	*F*	20	*5(5)*	7.5	20
8	*F*	22	0(2.5)	10	17.5
9	F	19	0	10	20
10	M	19	2.5	10	22.5
11	M	23	0	12.5	20
12	F	23	0(0)	5	15
13	*F*	22	2.5	7.5	15
14	M	20	5	12.5	25
15	F	21	0(0)	7.5	20
16	M	23	*2.5*	15	22.5
11	F	23	5	10	20
18	M	22	0(0)	0	10
19	M	21	0(0)	2.5	10
20	M	19	0	2.5	20
21	F	20	2.5(2.5)	15	23
22	F	26	5	15	25
23	F	20	5 (0)	10	20
24	*F*	19	0	7.5	20
25	F	19	2.5(0)	12.5	25
26	F	19	0	10	22.5
27	F	22	0(0)	10	25

continued.

continued

Subjects	Sex	Age	Adaptation score I KHZ 100 dB SPL	Adaptation score1KHz 110 dB SPL	Adaptation score 1KHz 120 dB SPL
28	F	23	5	10	22.5
29	M	20	0(0)	7.5	12.5
30	M	20	5	5	12.5
31	F	21	0	0	10
32	F	22	5	7.5	20
33	M	22	2.5	2.5	12.5
34	M	23	5	5	15

Mean= 21.64 Mean=8.89 Mean=18.16

S.D. = 2.3 S.D=3.89 S.D= 4.81

Figures in parenthesis indicate re-test values.

TABLE 6b

Adaptation values (in dB) with Mean and S.D., for simple adaptation at three intensities of 1000 Hz tone for 7-min exposure

Subjects	Adaptation 105 dB SPL	Adaptation 115 dB SPL	Adaptation 125 dB SPL
1	5(5)	10 (10)	20(20)
2	5(5)	10 (10)	20(20)
3	5(5)	5(5)	10(10)
4	0(0)	5(5)	10(10)
5	5(5)	10(10)	20(20)
6	5(5)	15(15)	30(30)
7	5	10	20
8	5(5)	5(5)	10 (10)
9	5(5)	10(10)	20(20)
10	5	15	
	Mean = 4.5 S.D. = 1.5	Mean = 9.5 S.D. = 3.5	Mean = 22.0 S.D. = 7.61

Figures in parenthesis indicate retest values.

The increase between 110 dB SPL, and 120 dB SPL was significant (X^2 = 39.9; df = 1. P < 0.001). This the Null Hypo, thesis - 4 (Intensity of the adapting stimulus has no significant effect on the amount of adaptation) can be rejected.

Experiment VIb

Table 6b gives the results of the experiment VIb. This expariment was conduction to study the growth of adaptation at high adapting intensities. Simple adaptation (adaptation measued at the base-line condition) was determined at adapting intensities of 105, 115 and 125 dB SPL. The duration of exposure waa 7-min. 10 subjects were tested. Mean adaptation values obtained for 10, adult subjects (6 F + 4 M) for adapting stimulus of 1 KHz tone adapted for 7-min at 105, 115 and 125 d SPL are 4.5 (S.D = 1.5); 0.5 (S.D = 3.5) and 22.0 (S.D = 7.6) respectively.

The results of experiments VIa and VIb show that adaptation increases with the increase in intensity of the adapting stimulus.

These results are in contrast to the results obtained in simultaneous Dichotic Loudness Balance (SDLB) method. (This point is thoroughly discoussed in chapter V).

Experiment VIIa

Adaptation valus (in ds) with Mean and S,D., obtained

TABLE 7a

Adaptation values (in dB) with Mean and S.D., obtained in two conditions with post-adapted test tone level of 100 dB SPL

subjects	sex	Age	Condition A Adaptation Value 1 KHz -105-7 min	Condition B Adaptationvalue 1 KHz - 115-7 min
1				
2	F	19	5	10(10)
3	F	20	7.5	10
4	F	20	5(5)	5
5	F	20	10 19	10(10)
6	F	22	2.5(5)	2.5
7	M	20	0	0
8	M	21	2.5	0(0)
9	F	20	7.5(5)	5(5)
10	F	19	5	5
11	F	19	7.5	7.5(5)
12	F	19	0	0
13	M	26	10(7.5)	10(10)
14	F	20	7.5	10
15	M	19	5(5)	7.5(5)
16	M	20	2.5	5
17	F	19	5	5
18	F	19	0 (2.5)	0
19	M	19	0	2.5(0)
20	M	19	5(5)	5
21	M	19	10	10 (7.5)
22	M	19	10(7.5)	10
23	M	21	5 (5)	0(5)
24	M	21	0	2.5
25	M	21	0	0(0)
26	F	22	7.5	5

continued...

Continued

Subjects	Sex	Age	Condition A* Adaptation value 1 KHz-105-7 min	Condition B** Adaptation value 1 KHz-1t5-7 min
27	F	21	5	5
28	F	21	0	0
29	F	21	5	7.5
30	F	21	10	10
31	M	22	5	5
32	M	22	0	2.5
		Mean=20.4	Mean=4.84 S.D.=3.53	Mean= 5.08 S.D =3.56

*Conditlon A: After adapting the ear using 1 KHz tone at 105 dB SPL for 7-min exposure, adaptation was measured at 100 dB SPL.

Condition B: after adapting the ear using 1 KHz tone at 115 dB SPL for 7-min exposure, adaptation was measured at 100 dB SPL.

figures in parenthesis indicate re-test valves.

in two conditions with post-adapted test tone levels of 100 d B SPL are presented in Table 7a, Condition A refers to the measurement of adaptation using a test tone of 1 KHz tone at 100 dB SPL, after adapting the ear to 1000 Hz tone at 105 dB SPL for 7-min. Condition B, refers to the measurement of adaptation using a test tone of 1 KHz tone at 100 dB SPL, after adapting the ear to 1000 ,Hz tone at 115 dB SPL for 7-min.

Mean adaptation values obtaiaed at 100 dB SPL (1 KHz) then the ear was adaptad to 1 KHz tone unnder the condition A and B are 4.84 (S.D = 3.53) and 5.08 (S.D = 3.56) respectively. The differances ware not significant (x2 = 0.5; df = 1; P > 0.5). Thirty-two subjects (18 F + 14 M) in the age range 19 to 26 Yrs (Mean age = 20.4) participated in this experiment.

from the above results, the Null Hypothesis -6 (see page -9) can be rejected.

Thus, the above results confirm small's (1963) prediotion that "If adaptation is mesaured at an intensity less than that of the adapting stimulus, it is found that the amount of adaptation does not depend upon the intensity at

TABLE 7b

Adaptation values (in dB) with Mean and S.D. obtained in two conditions with post-adapted test tone level of 105 dB

Subjects	Condition 1*	Condition 2**
1	15(15)	15(15)
2	10(10)	10(10)
3	20(20)	20(20)
4	15(15)	15(15)
5	25(25)	25(25)
6		
7	20(20)	20(20)
	Mean = 17.85	Mean = 17.85
	S.D = 4.51	S.D = 4.51

* Condition 1 - after adapting the ear using 1 KHz at 115 dB SPL for 4 min exposure, 1 adaptation was measured at 105 dB SPL.

** Condition 2 - after adapting the ear using 1 KHz tone at 125 dB SPL for 4-min exposure, adaptation was measured at 105 dB SPL.

Figures in parenthesis lindicate re-test values.

which the ear was adapted, but only upon the intensity at which adaptation is measured".

Experiment VIIb

Table 7b shows the adaptation values (in dB) (with Mean & SD), obtained in two conditions with post-adapted test tone level of 105 dB SPL. Condition 1 refers to the measurement of adaptation, using a test tone of 1 KHz tone at 105 dB SPL, after adapting the ear to 1000 Hz tone at 115 dB SPL for 4-min exposure, Condition 2, refers to the measurement of adaptation, using a test tone of 1 KHz at 105 dB SPL after the ear to 1000 Hz tone at 125 dB SPL for 4-min exposure.

Mean adaptation values are: 17.85 (S.D = 4.51) and 17.85 (S.D = 4.51) for the conditions 1 and 2 respectively.

These results confirm small's (1963) prediction even at high adapting intensities.

Experiment VIIc

To verify the Null Hypothesis-5 (See page-9)the experiment VIIc was carried out, The results of this experiment are presented in Table 7c. Xb and Xl values with Mean and S.D., for 38 subjects (21 M + 17 F) in the age range 19 to 24 Yrs (Mean age = 20.3) are shown in the table 7c X_b was measured at 110 dB SPL and X_b was datermined at 100 dB SPL.

TABLE 7c

X_b and X_L values (in dB) with Mean and S.D

Subjects	Sex	Age	X_b 1 KHz - 110 - 7 min measured at 110 dB SPL	X_L 1 KHz - 110 - 7min measured at 100 dB SPL
1	F	20	5 (5)	2.5
2	F	19	15	19 (7.5)
3	F	19	10	7.5
4	F	19	10	5(5)
5	M	20	10	7.5
6	M	19	12.5	7.5(5)
7	F	21	5	0
8	F	19	10	5(5)
9	F	19	10(7.5)	7.5
10	M	21	5	0
11	M	23	10	0(0)
12	M	24	7.5(10)	5(0)
13	F	19	10	7.5
14	F	22	2.5(5}	0(0)
15	F	22	7.5(5)	5(2.5)
16	F	20	5(5)	0(0)
17	F	19	12.5	5
18	M	20	10	5
19	M	20	5	5
20	M	20	5	5
21	F	21	12.5	5
22	M	20	5	0
23	M	21	5(5)	0(2.5)
24	M	21	5(5)	0
25	F	22	5(5)	0(0)
26	F	20	5(5)	2.5

continued...

TABLE 7c
continued

Subjects	Sex	Age	X_b 1 KHz - 110 - 7min measured at 110 dB SPL	X_L 1 KHz - 110 - 7min measured at 100 dB SPL
27	M	20	5	5
28	M	20	5	5
29	F	20	15 (12.5)	10
30	M	21	15	10
31	M	20	5	2.5
32	F	20	5	5
33	M	22	7.5	5
34	M	22	10(10)	5
35	M	21	10(10)	5
36	M	22	10(7.5)	7.5
37	M	22	5 (0)	0
38	M	21	5(5)	5
		Mean=20.3	Mean=7.96	Mean = 4.28
			S.D = 3.38	S.D. = 3.08

X_b - adaptation measured at the base-line condition.

X_L - adaptation, measured atca level lower than the baseline condition.

figure in parantheis indicate re-test valuses.

1 KHz tone at 110 dB SPL for 7-min was used as the adapting stimulus.

Mean X_b and Mean X_l values are: 7.96 (S.D = 3.38) and 4.28 (S.D. = 3.08) respectively.

Friedman test showed that the difference between X_b and X_L values was significant ($x^2 = 26.95$; df = 1 ; $P \leq 0.001$).

Thus the Null Hypothesis that there in no significant differance between X_b and X_L values, can be rejected.

This result corroborates the findings of other investigators with regard to Small's prediction (1963). X_L values are found to be less than X_b values.

Experiment VIIIa

Table 8a illustrates the results of the experiment VIIIa. This experiment was carried out to verify the Null Hypothesi-7 (there is no significan0t difference betweea X_b and X_h values). Forty-three subjects (19M + 24 F) in the age range of 19 to 25 Yrs (Mean age = 20.8) showed Mean X_b and Mean X_h values of 6.39 (S.D . 3.86) and 8.78 (S.D = 4.77) raspactively. 1 KHz tone at 110 dB SPL for 7-min was used as the adapting stimulus. X_h was measured at 120 dB SPL.

Friedman test showed significant difference between X_b

TABLE 8a
X_b and X_h values (in dB) with Mean and S.D.,

Subjects	Sex	Age	X_b 1 KHz - 110-7min measured At 110 dB SPL	X_h 1 KHz -110-7min measured at 120 dB SPL
1	M	22	0	
2	M	24	10(10)	10(10)
3	M	24	7.5(10)	15 (12.5)
4	M	21	7.5(10)	7.5(10)
5	M	20	10(7.5)	10 (10)
6	M	22	5	10
7	M	23	0	7.5
8	F	22	7.5	15
9	F	20	0(0)	5(5)
10	F	20	5	5
11	M	22	0	5
12	M	21	0	5
13	F	20	5(5)	12.5 (10)
14	F	20	5	0
15	F	19	12.5	20
16	F	20	5	5
17	F	20	15(12.5)	15(15)
18	F	20	10	5
19	F	22	5(5)	10(10)
20	M	20	5	10
21	M	21	5	5
22	F	20	5(5)	10(5)
23	F	19	15	20
24	F	19	10	5
25	F	20	10	10
26	M	25	10	15

continued....

continued

subjects	Sex	Age	X_b 1 KHz - 110-7min measured at 110 dB SPL	X_L 1 KHz - 110-7 min measured at 120 dB SPL
27	F	20	10	5
28	M	19	10	10
29	M	20	2.5(5)	10(10)
30	F	19	10	55
31	F	19	10	15
32	M	19	0(0)	5(5)
33	M	22	5	5
34	M	21	12.5	12.5
35	M	22	5	0
36	F	21	5	10
37	F	21	10	10
38	F	21	7.5(10)	10(5)
39	F	20	5	5
40	F	21	2.5	2.5
41	F	22	0(0)	2.5(5)
42	M	19	5	10
43	M	21	5	10

Mean=20.8 Mean=6.39 Mean = 8.78

S.D =3.86 S.D = 4.77

X_b -adaptation measured at the base-line condition.

X_h - adaptation measured at as intensity higher than the base-line condition.

Figure in paranthesis indicate re-test values.

and X_h values ($x^2 = 8.29$; df = 1; $P \leq 0.001$). Thirteen subjects showed: $X_h = X_b > 0$; 4 subjects showed: $X_h < X_b > 0$; 7 subjects showed: $X_h > X_b \leq 0$; and the remaining subjects (19) showed: $X_h > X_b > 0$.

Thus this experiment showed individual differences. The subjects Who showed no positive adaptation were considered to heve yielded '0' dB adaptation. On retesting. it was observed that all the seven subjects had 'Negative adaptation', Since the investigator was particularly interested in 'positive adaptation', whenever the subjects exhibited 'Negative adaptation' (increase in the 'magnitude of reflex' (or BM reading) for the post adapted test tone), he had considered the adaptation as '0' dB; Hence, '0' dB adaptation reported in this experiment was actually 'Negative adaptation'. The exact amount of Negative adaptation', was, however, not recorded.

Since significant differences between X_b and X_h values vere observed, the Nall Hypothesis-7 (there is no significant difference between X_b and X_h values) can be rejected.

The results of this experiment and the result of subsequent experiments led the investigator to propose a revised model for loudness coding during auditory adaptation. Further discussion on the results of this experiment and the subsequent experiments follows in the next chapter (Chapter V).

Experiment VIIIc

Table 8c shows the results of the experiment VIIIc. This experiment was conducted to ensure that the results: $X_h > X_b > 0$ was not due to any experimental error. X_b and X_h values (8 trials on the same subject - the investigator) are presented in tha Table 8c. in all the 8 trials (16 adaptation teats on different days) X_h is consistently more than X_b. X_b was measured using 1 KHz tone at 110 dB SPL for 7-min. X_h was measured at 120 dB SPL.0 Table 8c shows that the mean values of X_h and Xb are: 15.93 (S.D = 1.21) and 10.62 (S.D = 1.08) respectively. Thus this experiment confirmed that the result: $X_h > X_b > 0$ was a reality and that it was not due to any experimental error.

Experiment VIIIb

Table 8b shows the results of this experiment. X_b and Xh values (with Maan ans S.D) are given in the Table 8b. X_b was determined using 1 KBz tone at 120 dB SPL for 4-min as the adapting stimulus. Xh was determined using 1 KHz at 130 dB SPL as the test tone. Five adult subjects (3 F + 2 M) were tested in this experiment.

Mean values of X_h and X_b are: 4.0 (S.D = 4.89) and 13.0 (S.D = 4.0) respectively.

TABLE 8b

X_b and X_h values (in dB) with
Mean and S.D.

Subjects	X_b 1 KHz - 120 - 4 min measured at 120 dB SPL	X_b 1 KHz - 120 - 4 min measured at 120 dB SPL
1	15(15)	10(10)
2	20(20)	10 (10)
3	10(10)	0 (0)
4	10(10)	0 (0)
4 5	10(10)	0 (0)
	Mean = 13.0	Mean = 4.0
	S.D = 4.0	S.D =4.89

X_b - adaptation measured at the base-line condition.

X_h - adaptation measured at an intensity higher than the base-line condition.

Figure in the parenthesis indicate re-test values.

TABLe 8c

X_b and X_h values (in dB) with Mean
and S.D., data obtained
on a single subject

Number of trial*	X_b 1 KHz - 110 - 7-min measured at 110 dB-SPL	X_b 1 KHz - 110 - 7-min measured at 120 dB SPL
1	10	15
2	10	15
3	12.5	17.5
4	10	17.5
5	10	15
6	12.5	17.5
7	10	15
8	10	15
	Mean= 10.62 S.D = 1.08	Mean = 15.93 S.D = 1.21

X_b - adaptation measured at the base-line condition.

X_h - adaptation measured at an intensity higher than the base-line condition.

Thus this experiment showed: $X_h < X_b > 0$. This means that the result: $X_h < X_b > 0$ expected at very high adapting intensities.

Experiment VIIId

Table 8d gives the results of the experiment-"VIIId. This experiment is similar to the experiment VIIIb. X_b and X_h values were obtained on the same subject (the investigator - 6 trials) usind very high adapting intensity. Xb was measured using 1 KBz tone at 125 dB SPL for 7-min. X_h was measured using 1 KBz test tone at 135 dB SPL. Mean X_b and X_h values are: 20.83 (S.D = 1.18) and 11.25 (S.D = 3.01) respectively.

Thus the result : $X_h < X_b > 0$, can be expected at very high adapting intensity.

Experiment IXa

Experiment IXa was done to have normative data regarding recovery time from adaptation to 0.5 KHz tone at 115 dB SPL for 3-min exposure. Table 9a gives the results of the experiment. Thirty two subjects (21F + 11M) ranging in age from 19 to 22 Yrs (Mean age = 21.1) were tested. Mean adaptation was 3.52 (S.D = 2.97). Nearly 50% of the subjects showed complete recovery within a minute. This data might be useful if a diagnostic test based on recovery time

TABLE 8d

X_b and X_h values (in dB) with Mean and S.D., (data obtained on single subject using very high adapting intensity

Numberof trials	X_b 1 KHz - 125 - 7-min mesured at 125 dB SPL	X_h 1 KHz - 125 - 7-min mesured at 125 dB SPL
1	22.5	15
2	20	10
3	20	10
4	22.5	10
5	20	-
6	20	-

Mean = 20.83 Mean = 11.25

S.D = 1.18 S.D. = 3.01

TABLE 9a

Adaptation values (in dB) (with Mean and S.D) and recovery time, for 500 Hz tone adapted for 3 min at 115 dB SPL

Subjects	Sex	Age	X_b 0.5 KHz - 115-3min measured at 115	Recovery time in minutes
1	F	19	7.5	<3
2	F	19	5	< 3
3	F	20	0	-
4	M	20	10(5)	< 3 (<3)
5	F	20	0	-
6	F	1 9	0(0)	-
7	F	20	0	-
8	F	20	2.5(2.5)	<1(<1)
9	F	19	2.5	<1
10	M	22	5 (5)	<1(<l)
11	F	20	2.5	< 1
12	F	22	2.5	< 1
13	F	20	2.5(2.5)	<1(<1)
14	M	21	5	<2
15	M	19		< 2
16	F	21	5	-
17	M	20	0 0	-
18	F	21	2.5	<1
19	F	22	5	<2
20	F	21	7.5(5)	<2(<2)

continued

Subjects	Sex	Age	X_b 0.5 KHz - 115 - 3 min measured at 115	Recovery time in minutes
21	F	20	7.5	< 1
22	F	19	2.5	< 1
23	M	22	2.5(5)	< 1
24	M	20	5	< 1
25	M	21	7.5(5)	< 3(<3)
26	F	22	5	<1
27	F	19	2.5	<1
28	M	22	10	<2
29	F	21	5	<1
30	F	20	0(2.5)	-(<1)
31	M	22	0	-
32	M	20	0	-
		Mean = 21.1	Mean = 3.32 S.D = 2. 97	Range 1 to 3

Figure in paranthesis indicate re-test values.

for detecting retrocochlear pathology cases would prove to be feasible.

Experiment IXb

Experiment IXb was carried out to know whether the recovery time is dependent on the frequency of the test tone. Since the experiment IVc ("cf. PP.79-80") showed that the frequency of the adapting stimulus may have negligible effect on the amount of adaptation, provided the loudness of the adapting stimulus is taken into account, (instead of the intensity of the adapting stimulus) 500 Hz and 1000 Hz tones were presented at equal loudness level(equal magnitude of reflex) to study the recovery time. These tornes were presented (separately) at 125 dB SPL for 7-min. Adaptation and recovery time were measured. This experiment was carried out on a single Subject (the investigator) 12 times on different days. From the table 9a,Mean adaptation values with S.D for 1 KHz and 500 Hz tones arr: 20.830 (S.D = 1.18) and 15.41 (S.D = 0.93) respectively. The recovery time for 1 KHz varied from 5 to 7-min. The recovery time for 0.5KHz varied from 2 to 3 min. (in one trial the recovery tone was nearly 4-min).

Thus the results show that the recovery time at 500 Hz is rapid. the difference in the amount of adaptation observed at 500 Hz and 1000 Hz adapting tones may be due to the

TABLE 9b

Adaptation and recovery time for 500 and 1000 Hz adapting tones at 125 dB SPL

Number of trials	1KHz - 125 - 7-min measured at 125 dB SPL		0.5 KHz - 125 - 7 min measured at 125 dB SPL	
	Adaptation in dB	Recovery time in minutes	Adaptation in dB	Recovery time in minutes
1	20	> 5 < 6	15	>2<3
2	22.5	> 5 < 6	15	>2<3
3	20	> 6 < 7	17.5	>3<4
4	22.5	> 6 < 7	15	>2<3
5	20	> 5 < 6	15	>2<3
6	20	> 5 < 6	15	>2<3

Mean=15.41

Mean = 20.83 Ranged 5 to

S.D.=0.93

Range 2 to 4

rapid recovery which takes place at 500 Hz. As the technique (ORMLA) requires 5-sec rest period i.e, after the withdrawal of the adapting stimulus; this rest period might be responsible for less amount of adaptation observed at 900 Hz.

Thus there appears to be a 'frequency effect' in recovery from adaptation.

Experiment IXc

Experiment IXc was carried cut to know whether recovery time like adaptation, would be less when the recovery time was measured using a test tone of intensity lower than the adapting intensity. Table 9c gives the results of the experiment.

Recovery time was measured in two conditions : (1) Adapting the ear using 1 Khz tone at 125 dB SPL for 7-min and measuring the recovery time using 1 Khz test tone at 125 dB SPL and (2) Adapting the ear using 1 KHz tone at 125 dB SPL for 7-min and measuring the recovery time using 1 KHz test tone at 110 dB SPL.

The above experiment was done on a single subject (the investigator - 8 trials or 13 (8 + 5) adaptation tests) on different days.

TABLE 9c

Recovery time measured in two conditions

Number of trails	Condition 1 1 KHz - 125 - 7-min measured at 125 dB SPL	Condition 2 1 KHz - 125 - 7 min mesured at 110 dB SPL Recovery time in Minutes
1	>5<6	>2<3
2	> 5 < 6	>2<3
3	>6<7	>2<3
4	>6<7	>2<3
5	> 5 < 6	>2<3
6	> 5 < 6	-
7	>6<7	-
8	>5<6	-

TABLE 9d
Recovery time and adaptation values at
three adapting intensities

Number of trials	Condition '1' 1KHz-100-7 Min		Condition '2' 1KHz-110-7 Min		Condition '3' 1 KHz-125-7 Min	
	Adaptation in dB	Recovery time in minutes	adaptation in dB	Recovery time in minutes	Adaptation in dB	Recovery time in minutes
1	5	>1 < 2	10	> 2 < 3	22.5	>6 < 7
2	5	< 1	12.5	> 4 < 5	20	>5 < 6
3	2.5	< 1	10	> 2 < 3	20	>6 < 7
4	5	< 1	7.5	>2 <3	22.5	>5 < 6
5	5	> 1 < 2	12.5	> 4 < 5	25	>6 < 7
6	7.5	> 2 < 3	12.5	> 4 < 5	20	> 5 < 6
7	5	> 2 < 3	10	> 5 < 4	22.5	> 5 < 6
8	7.5	> 2 < 3	10	> 3 < 4	25	> 6 < 7
	Mean = 5.31 S.D = 1.49	> 2 < 3	Mean=10.62 S.D = .65	>2 < 5	Mean=22.2 S.D = 1.95	range 5 to 7

From the table 9C, It is clear that the recovery time, like adaptation, is also reduced when the recovery time was measured using the test tone of intensity lower than the adapting intensity. Thus, the results of this experiment reveal that small's (1963) prediction holds good for recovery time also.

Experiment IXd

Experiment IXd was done to determine whether recovery time Increases with the increase in the amount of adaptation. Adaptation and recovery time were measured using three adapting intensities viz., 100, 110 and 125 dB SPL. 1 KHz tone (7-min exposure) was used as the adapting stimulus. Table 9d illustrates the results of the experiment.

It is clear from the Table 9 d that the recovery time increases with the increase in the amount of adaptation. Recovery time (2 to 3 min) observed in condition '1' has increased to 5 to 7-min in condition '3'.

Thus it can be concluded that the time required for complete recovery from adaptation is dependent upon the amount of adaptation.

Reliability Tests

To check the reliability of tha rasults obtained in all the above experiments, 8 to 16 subjects, belonging to

TABLE 10

Summary of test and re-test data (with pearsons 'r' of oorrelation between test and re-test data) of majority of the experiments

Sl. No.	Experiment No.	Description of the data	Test Data Mean (in dB)	Re-test data Mean (in dB)	'r'	Value of 'r' required for significance at l% level of significance	at 5% level of significance
1	2	3	4	5	6	7	
1	IIa	'BMreadings' at 110 dBSPL of 1 KHz tone	6.56 (not in dB)	6.68 (Not in dB)	0.99	0.83 (df=6)	
2	IIIa	Adaptation 2KHz-110-3	5.83	5.62	0.829	0.708 (df=10)	
3	IVb	(See VIIc)					
4	Va	1K-110-3' 1K-110-3' measured at 2 KHz	5.75 3.86	5.5 2.95	0.78 0.68	0.76 (df=8) 0.73 (df=9)	 0.6 (df=9)
5	VIa	1K-100-3'	1.07	1.07	0.94	0.66 (df=12)	
6	VIb	1k-105-7' 1K-115-7' 1K-125-7'	4.5 9.5 22.0	4.5 9.5 22.0	1.0 1.0 1.0	0.7 (df=8) 0.7(df=8) 0.7(df=8)	
7	VIIa	1K-125-7' condition A 1K-115-7' condition B	6.0 5.68	5.75 5.22	0.87 0.88	0.76(df=8) 0.73(df=9)	
8	VIIb	Condition 1 Condition 2	17.85 17.85	17.85 17.85	1.0 1.0	0.87(df=5) 0.87(df=5)	

continued..,

continued

1	2	3	4	5	6	7	8
9.	VIIIc	X_b	7.03	6.41	0.80	0.62 (df=14)	
		X_L	3.27	2.68	0.7	0.68 (df=11)	
10.	VIIIa	X_b	5.77	6.15	0.92	0.68 (df=11)	
		X_h	9.42	8.65	0.78	0.68 (df=11)	
11.	VIIIb	X_b	13.0	13.0	1.0	0.96 (df=3)	
		X_h	4.0	4.0	1.0	0.96 (df=3)	
12.	IXa	0.5K-115-3'	3.75	3.25	0.79	0.76 (df=8)	

Code : adapting frequency - adapting intensity - duration of adaptation.

each expariment, were retested on different days. Test and re-test data of the majority of the experiments are presented in a summmarized form in Table 10. Pearsons 'r' correlation between test and retest data and significance of correlation at 5% or 1% 1eva1 of confidence are also presented in the Table 10.

From the Table 10, it is clear that the test and re-test data show very high correlation--significant at 1% level of confidence in all the experiments (except Va, which shows significance at 5% level of coanfidence).

CHAPTER V

GENERAL DISCUSSION

The results of the experiment VIIIa showed that the subjects differed considerably in their performance--that is, there was inter subject variability when adaptation was measured at an intensity higher than the adapting intensity. Among the 43 subjects tested, 19 subjects showed: $X_h > X_b > 0$; 13 subjects showed: $X_h = X_b > 0$; 4 subjecats showed: $X_h < X_b > 0$ and 7 subjects showed $X_h > X_b < 0$. Friedman test showed significant differance between X_h and X_b values ($x^2 = 8.29$; df = 1; $P < 0.001$). Majority of the subjects showed $X_h > X_b > 0$.

The about results are quite intaresting as, such types of results are not reported by any lavestigator using the techniques which are commonly used for measuring adaptation. However, a recent study by Class and Weiler (1979) showed no significant difference between X_h and X_b values.

The results of the preseat study are quite contrary to the results reported in the literature.

Gless and Weiler (1979) discussed their results in the following manner, "several characteristics of the present study may have contributed to the results. The subjects were older than previously, although not greatly so. The monaural balance technique has generally been less stable and more difficult than binaural simultaneous balance technique, and frequencies are different. It is also possible as suggested by Weiler and Davis (1975) that the monaural technique measures a different auditory change due to adaptation then that measured by simulitanus binoural balances".

The result of the experiment VIIIb & VIIId showed: $X_h < X_b > 0$. In these experiments very high adapting intensity was used; hence, the reasults: $X_h < X_b > 0$ can be expected at very high adapting intensity.

When all the above results are carefully scrutinized, the following observation would be obvious:(1) presence of inter-subject variability for X_h and X_b values under similar experimental conditions. (2) $X_h < X_b > 0$, results consisently when the adaptation intensity is very high (120 dB SPL). (3) $X_h > X_b > 0$, results when the adapting intensity is not Very high, and (4) Seven subjects in the experiment VIIIa show $X_b < 0$ ("of. PP 96-99").

The above observations gavae cluss to the investigator to think of the possible explanations for the obtained results. Meanwhile, several questions had to be answered:

(1) Why was the result: $X_h < X_b > 0$ observed consistently at very high adapting intensity only?

(2) What could be the explanations for the following results? - $X_h > X_b > 0$; $X_h = X_b > 0$; $X_h > X_b \leq 0$ (since these results are contrary to small's (1963) prediction)

(3) Why was the result: $X_h < X_b = 0$ not observed in any of the subjects tested?

(4) What could be the reasons for the obtained results: $X_L < X_b > 0$, which concurred with Small's prediction.

(5) What could be the explanation for the 'Frequency Effect' observed with regard to the recovery time? i.e., why was the recovery time rapid for 500 Hz test time?

(6) Why did the 'negative adaptation' ($X_b < 0$) result at moderate adaptiing intensity only?

&(7) What could be the auditory mechanism for the increase in loudness of the post adapted test tone?

The moment, the investigator realised that the 'negative adaptation' was perhaps the main 'culprit' for the results: $X_h > X_b > 0$, the task become very easy to find answers to the above mentioned questions. Loudness coding during anditory adaptation was visualised through the equatlon derived from the obtained data.

The important observation in seven subjects of experiment VIIIa) that the loudness of the post adapted test tone increased when the post adapted test tone was presented at the base-line lntensity (adapting intensity)and that the loudness of the post-adapted test tone decreased when it was presented at an intensity higher than the adapting intensity, was a clear evidence for the different auditory mechanisms involved. In other words, the auditory mechanisums involved in the perception of loudness of the post adapted test tone at base-line intensity and at a level higher than the base-line intensiy are quits different. The fact that the loudness of the post adapted test tone at the base-line intensity (L_{tba}) was greater than the loudness of the pre-adapted test tone at the base-line intenasity (L_{tbb}) showed that there was 'facilitatory' effect (increasing the loudness of the test tone) when the test tone at the base-line intensity (adapting intensity) was presented to the ear daring the post-adapted condition. On the other hand, the fact that the loudness of the post adapted test tone at an intensity higher than the adapting intensity (L_{tha}) was less then the loudness of the pre-adapted test tone at an intensity higher than the adapting intensity (L_{thb}), showed that there was no 'facilitatory' effect (but instead there was 'loudness decreasing' effect).

In brief, it can be interpreted as follows:

1. L_{tba} - L_{tbb} (loudness increase after adaptation) is due to the 'facilitatory effect',

2. L_{thb} - L_{tha} (loudness loss) is due to the absence of the 'facilitatory effects and also due to the presence of loudness decreasing effect.

the above interpretation make it clear that the 'facilitatory effect' operates when the post-adapted test tone is presented at the adapting intensity and that the 'facilitatory effect' disappears when the post-adapted test tone at an intensity higher than the adapting intensity is presented. Since $L_{tha} < L_{thb}$, the 'loudness decreasing effect' must be operating when the post-adapted test tone at an intensity higher than the adapting intensity is presented.

The result: $X_h > X_b > 0$ obesrved in 19 subjects of experiment VIIIa shows that in these subjects there was loudness loss when the post adapted test tone was presented at the baseline intensity i.e., $L_{tba} < L_{tbb}$. This means that the 'loudness decreasing effect' must be operating whan the post adapted test tone was presented at the base-line intensity.

Thus, it is obvious that the 'loudness decreasing effect' must operate during both (base-line and at higher intensity than the base-line) post-adaptation measurements.

The above points have revealed that the moment the post adapted test tone at an intensity higher than the adapting intensity is presented, the 'facilltatory effect' will not be available, but instead the 'loudness decreasing effect' will be operating. The 'loudness decreasing effect' may be viewed in terms of reduction in the number of activated neural units. The 'facilltatory effect' can be viewed in terms of 'increase' in the number of activated neural units.

Thus, the 'loudness decreasing effect' appears to be clear, When am auditory stimulus is presented continuously, some of the neural units become less sensitive and cease to respond (adaptation process). The decrease in the number of activated neural units, due to the adaptation process, is mainly responsible for $L_{tha} < L_{thb}$ Since the 'adapted neuralunits'areresponsibleforL$_{tha}$<L$_{thb}$,itmaynotbe correct to assume ("cf. pp 31-37 "), that all the adapted neural units would be reactivated by the post-adapted test tone at an intensity higher than the adapting intansity. "small (1963) hypothesized that a test tone of greater intensity than the adapting tone would excite more elements than the adapting stimulus. A test tone of this nature would excite previously adapted units, and some non-adapted units, The prediction was that less adaptation should be measured when the test tone exceeded the adaptimg tone intensity, than when test and adapting stimuli were of equal intensity" (Weller and Hood, 1977).

Thus, Small's assumption as reported by Weller and Hood (1977) needs to be revised in the light of the data of the present study.

The consistent result: $X_h < X_b > 0$, obtained in the experiments VIIIb and VIIId at very high adapting intensity.

should be interpreted in the light of the results as discussed above. From the previus discussion it is clear that the 'adapted neural units' operate while X_b and X_h measurements. During X_b measurements, both 'adapted neural units' and the 'facilitatory effect' will be operating. Since the 'facilitatory effect' disappears when the post-adapted test tone at an intensity higher then the adapting intensity is presented, it must be of 'unstable' nature. On the other hand, since the 'adapted neural units' are not reactivated by the post-adapted test tone at an intensity higher then the adapting intensity, these adapted units must be of 'stable' nature.

The fact that the 'facilitatory effect' results due to continous auditory stimlation, this may be due to the function of 'unstable' adapted neural units. Thus it is reasonable (as the data and the discussion suggest) to assume that the 'unstable adapted' neural units would be reactivated when the post-adapted test tone at an intensity higher then the adapting intensity is presented and that the 'stable' adapted neural units will not be reactivated by the post adapted test tone at an intensity higher then the adapting intensity.

At this point, it is clear that there exists at least two types of adapted neural units: (1) 'stable' adapted neural units (a) & (2) 'unstable' adapted neural units (a').

Further explanatlons for the obesrved resulte in the present study can be best illustrated through the equation.

Adapted nearal unit (A) = Stable adapted neural units

(a) + Unstable adapted neural
units (a'). OR

$A = a + a'$ .... eq 1.

Loudness of a test tone at the adapting intensity (base-line condition) before adaptation (L_{tbb}).
= Adaptable neural unite (A) + Unadaptable neural units (U).
OR $L\ tbb = A + U$ . . . eq. 2

Loudness of a test tone at the adapting intensity (Base-line condition) after adaptation (L_{tba}).
= + unadapted neural units (U).
0R $L_{tba} = U$ . . . . . . eq. 3.

Loudness loss at the base-line intensity ($L_{tbb} - L_{tba}$)= X_b =
$A + U - U = A$

OR $L_{tbb} - L_{tba} = X_b = A$

OR $X_b = a + a'$ ($\because$ $A = a + a'$) .... eq. 4

Loudness of a test tone at an intensity higher then the adapting intensity, before adaptation (L_{thb})

= Extra neural units activated by the test tone higher in intensity than the test tone at the adapting intensity (E) + A + U

OR $L_{thb} = B + A + U$ . . . eq 5.

Loudness of a test tone at an intensity higher than the adapting intensity, after adaptation (L_{tha}) = E + unstable adapted neural units (a') + U

OR $L_{tha} = E + a' + U$ . . . . eq. 6.

(because unstable adapted neural units will be reactivated by the post-adapted test tone at an intensity higher than the adapting intensity).

Adaptation measured at an intensity higher than the base line intensity (X_h) = $L_{thb} - L_{tha} = E + A + U - E - a' - U = a$

OR $X_h = a$ . . . . eq. 7.

<---------->

The results of the experiments VII a, VII b, and VII c, confirmed small's (1963) hypothesis that, "if adaptation is measured at an intensity less than that of the adapting stimulus, it is found that the amount of adaptation does not depend upon the intensity at which the ear was adapted, but only upon the intensity at which adaptation is measured".

The resalt: $X_L < X_b > 0$ can be explained as follows:

Loudness of test tone at an intensity lower than the baseline intensity, before adaptation (L_{tlb}) = Adaptable neural units at an intensity lower than the adapting intensity {A_l).

OR $L_{tlb} = A_l + U_l$ . . . . eq. 8.

A test tone of lesser intensity than the adapting tone intensity exites fewer auditory elements and thus less adaptation appropriate to the test tone intensity results (Small 1963).

Loudness of a test tone at an intensity lower than the adapting intensaity, after adaptation (L_{tla}) = U_l

OR $L_{tla} = U_l$ . . . eq. 9. (.'. the post adapted test tone at an intensity lower than the adapting intensity cannot re-activate the unstable adapted neural units).

.'. Adaptation measured at an intensity lower then the adapting intensity (X_l) $= L_{tlb} - L_{tla} = A_l + U_l - U_l = A_l$

0R $X_l = a_l + a_l$ . . . eq. 10 (because $A_l = a_l + a_l$)
where al is the stable adapted neural units at an intensity lower then the adapting intensity and a_l is the unstable adapted neural units at an intensity lower then the adapting intensity.

Using the derived equation viz., $xb = a + a'$ ... eq. 4

$X_h = a$ ... eq. 7

$X_l = a_l + a_l$ .. eq. 10

the different results obtainad in the present study can be explained.

(1) $X_h > X_b < 0$

$a > a + a' < 0$

.'. The necessary conditions for this results are : (1) a' < 0 (ii) a <-a'. a'< O imndicated that the unstable adapted neural junita is negative, i.e., these unstable adapted neural units can be designated "Negative unstable adapted neural unite". These units are responsible for the increse in the loudness of the post adapted test tone presseted at the base-line intensity. In other words, these negative unstable adapted sevral units (-a') are responalble for the "facilitatory effect' (negative adaptation) observed in seven subjects of the experiment VIIIa. Since $X_b < 0$, can be expected at moderate adapting intensities only, it is reasonable to assume that -a' units are associated with moderate intensity of the adapting stimulus. It is well known that the outer hair cells respond to lew intansity sound; hence, it is quite possible that the neural units innervating the outer hair cells may be a source of -a' units The function of -a' units is to increase the loudness of the post adapted test tona at the base-line intensity. This is possible only when extra neural units are activated during the continuous auditory stimulation, These extra activated neural units must be the same as the negative unstable adapted neural units. Since the source of -a' units may be the neural units innervating the outer hair cells (as discussed earlier)a link between -a' units and the efferent system innervating the outer hair cells can be reasonably guessed. This deduction can be further strengthened by the fact that the efferent system is known for 'inhibitory' activity.

Negative adaptation can be viewed as 'inhibition' of adaptation prcess. When adapting stimulus of moderate intensity is presentad continuously to the ear, the efferent system innervating the outer hair cells may start activating the sensory inputs - thus thera will be extra activated neural units during the post adapted condition. The above discussion points out that the action of the efferent system inneravtion the outer hair cells may be responsible for the extra activated neural units which in turn are responsible for $L_{tba} > L_{tbb}$. Thus this efferent action tries to 'inhibit the adaptation process by activating additional sensory inputs.

This 'vital' information that the efferent system innervating the outer hair cells 'activates' the sensory inputs while the adaptation process goes on, appears to be a 'break-through' in auditory physiology.

From the above deduction, it is clear that the -a' units originate from the action of the efferent system innervating the outer hair cells. The fact that the 'facilitatory effect' (resulting from -a' units) disappeara at an intensity higher than the adapting intensity clearly above that the 'facilitatory effect ' has some link with the efferent system innervating the outer hair cells. The efferent action can be expected to cease the moment the post adapted test tone at an intensity higher than the adapting intensity is presented; hence, the link between -a' units and the action of the efferent system innervating the outer hair cells seems to be justified. The moment the higher auditory centres get the information that the adaptation process (gradual decrease in the number of activated neural units), is going on, the efferent system will be activated. To compensate for the decrease in the neural activity due to the adaptation, process gradually the efferent nerve ending (innervation the outer hair cells) will become active (it is well known that the efferent innervation have control over sensory inputs). Consequently, there will be a gradual increase in the number of impulsis reaching the auditory centres. Due to the adaptation process, there will be a gradual decrease in the nuwber of impulses reaching the auditory centres, but simultaneously with the adaptation process, there will be a gradual increase in the number of impulses reaching the auditory centres due to the efferent action (inhibition process). The efferent action is to inhibit the adaptation process. The results of the pressent study clearly show that the 'adaptation process' is not inhibited (by the action of the efferent system innervating the outer hair cells) by means of preventing the neural units getting adapted, but instead, the adaptation process is inhibited (by the efferent action) by means of activation of additional sensory units (afferent neural units innervating the outer haif cells).

(2) $X_h > X_b = 0$

$a < a+a' = 0$

.'. The necessary conditions for this results are:

(i) $a' < 0$ & (ii) $a = -a'$

Thus the rasult: $X_h > X_b = 0$ is due to the presence of negative adapted neural units and stable adapted neural units. Both these units are in equal proportion.

(3) $x_h = X_b + 0$
$a = a + a' = 0$

.'. The necessary condition for this result are: (1) $a' = 0$
(ii) $a = 0$ & (iii) $a = -a'$.

(4) $X_h > X_b > 0$

$a < a + a' > 0$

.'. The necessary conditions for this result are:

(1) $a' < 0$ & (ii) $a > -a'$.

(5) $X_h < X_b > 0$

$a < a+a' > 0$

.'. The necessary condition for this result are: (1) $a' > 0$
(ii) $a > -a'$ a (iii) $a > 0$.

$a' > 0$ shows that unstable adapted neural units are "positive unstable adapted neural units". Thus it appears that there are two types of unstable adapted neural units vis., positive unstable adapted neural units (+a') and negative unstable adapted neural units (-a')

Since the result $X_h < X_b > 0$ was observed consistently at very high adapting intensity, it is quite possible that the neural units innervating the inner hair cells may be a source for +a' units (it is well known that the inner hair cells respond to high intensity sounds). Further $a + a' > 0$ shows that the contribution of -a' units to the loudness of the post-adapted test tone at the base-line intensity can be considered insignificant.

As +a' units originate from the neural units innervation the inner hair cells, it is quite possible that the function of these units may be quit contrary to the0 -a' units (for more discussion on this aspect see pp.).

(6) $X_h < X_b = 0$
$a < a+a' = 0$
.'. The necessary conditions for this results are:
(i) $a' > 0$ and (ii) $a = a'$.

This result was not observed in any subject and the two conditions could not be satisfied. From the previous results, it is clear that $a = -a'$ can be expected at moderate intensities of the adapting stimulus, whereas $a' > 0$ can be expected at very high adapting intensities ("of pp 129-130"). Since the condition $a = -a'$ requires moderate intensity of the adapting stimulus and the condition: $a' > 0$ requires very high adapting intensity, the co-existence of these two conditions in a subject to produce the result: $X_h < X_b = 0$, is impossible.

(7) $X_l < X_b > 0$

From eq. 10, $a_l + a_l < a + a' > 0$

.'. The necessary conditions for this result are : (1) $a_l + a_l < a + a'$ (ii) $a > -a'$, Since $al + a_l < a + a_l'$, the result $X_l < X_b > 0$ was observed consistently in all the subjects tested.

Experiment IXb showed that the recovery from Adaptation at 500 Hz was more rapid then the recovery from adaptation at 1 KHz. This result suggests that (a) units originate from different regions of the basilar membrane. It may be reasonable to assume that the place of maximum stimulation on the basilar membrance is the source for (a) units (stable adapted neural units). "simple Category' and 'Complex Category' (terms used by Frishkepf and Goldstein (Teas,1970) may be the source for (a) units i.e., (a) units for low frequecies may originate from 'Camplex Category' and (a) units for $\geq$ 1KHz may criginate from 'Simple Category'.

"+a'" and "-a'" may be linked to "R_2" and "R_1" processes (respectively) reported by Hirsh and Bilger (ward,1963) in connection with 'bounce' phenomenon observed within 2-min of recovery time during TTS experiments. Thus the present study supports Hirsh and Bilger's hypothesis that 'bounce' phenomenon is a neural phenomenon.

Possible Mechanisms of perstimulatory Adaptation (Concomitant-binaural

Adaptation measured using Simultanious Dichotic Loudness Balance Method (SDIB) is Known as 'perstimulatory-adaptation'. (or concomitant binaural).

Ward (1973) has concluded that, "perdtimulatory adaptation reflects a changes in the 'potency' of stimuli in regard to localization following monsural stimulaton it is demonstrable only by binaural presentation of test signals and therefore involves complex judgemental processes relatively high up the auditory chain (though the possible efferent action of monaural stimulation on the periphery of the contralateral auditory stimulation canaot be ruled out)....For the moment, perstimulatory adaptation remains a provoking enigma".

Using the deductions drawn from the results of the present study and using too data available for Monaural Heterophonic (MH) technique and SDLB technique, it may be possible to understand the mechanism involved in 'perstimulatory adaptation'.

The reason for using the data of MH technique instead of the data of ORMLA technique is that the former measures 'concomitant' adaptation and the latter measures 'residual' adaptation. Since 'perstimulatory adaptation' is 'concomitant' adaptation, the data of ORMLA are not compared with the data of SDLB technique. The mechanisms of perstimulatory adaptation can be understood if the answers to the following questions are known:

1. Why do we observe $X_h < X_b > 0$, when the adapting intensity is $\leq$ 60dB SPL, in SDLB method?

2. Why do we observe levelling off of adaptation aboue 60 dB SPL, in SDLB method?

3. Why do we observe $Xh < X_b > 0$,when the adapting intensity is about 60 dB SPL, in SDLB method?

Since the deductions from the results of the present study are from a monaural technique (ORMLA) these deductions cannot be applied straighbtaway to the available data of SDLB method. Therefore, it is necessary to consider the adapting ear and the comparison ear separately. After Knowing the conditions which prevail (during the post-adapted conditions) in the two ears, the combined effects can be reasonably prodicted.

Regarding the question—-why do we observe $X_h < X_b > 0$ in SDLB technique at 60 dB SPL adapting intensity, the answer may be obtained as follows:

Available data for MH technique at an adapting intensity of 60 dB SPL is Xb = 11.75 dB (Mean) (Weiler et al 1977). from the deductions of the present study, the condition required for $X_b > C$ is $a + a' > 0$ or $a > -a'$. Thus, $a > -a'$ can be expected in the adapting ear during the post-adapted condition of SDLB method. Since the cross-over of the adapting stimulus to the comparison ear at 60 dB SPL is negligible, adaptation of the comparison ear may be ruled out. For convenience it can be assumed that the adapting ear and the comparison ear are identical during preadapted balances.

The available data for SDIB at 60 dB SPL adapting intensity is 20 dB (Mean) (Weiler, 1972). Thus it follows that SDLB method yields $X_b > 0$ i.e., the comparison of the data available for MH technique and the data of SDLB, shows that X_b (SDLB) > X_b (MH) (i.e, 20 > 11,75). the fact that SDLB method yields more adaptation than the MB technique at identical interelty and at identical adapting period, is an indication for the influence of the comparison ear in the results. Weiller et al (1979) showed no significant correlation between the amounts of adaptations obtained for MH and SDLB techniques an the same subjects. Glass and Weiler (1979) observed that MH technique and SDLB techique yieded: $X_h = X_b > 0$ and $X_h < X_b > 0$ respectively for nearly the same stimulus parameters (Weiler et al 1972). Thus the above finding show that ADLB and MH techniques yield different results although both measure concomitant adaptation. The difference in the results obtained in the two methods must ba due to the influence of the comparison ear.

Since adaptation of the comparison ear through cross-over of the adapting stimulus (60 dB SPL) can be considered negligible, the influence of comparison ear (CE) can be expected through 'binaural interaction', The results X_b (SDLB) > X_b (MH) can be expected provided $*L_{tba} > *L_{tbb}$ (loudness of the post-adapted test tone in the comparison ear loudness of the pre-adapted test-tone in the oomparison ear. But, $*L_{tba} > *L_{tbb}$ can be expected only when $*X_b < 0$ i.e., *-a' results in the comparison ear. This means that 'negative adaptation' (or action of the efferent system innervating the outer hair cells "cf.pp.125-128") must be present in the comparison ear. In this context, the author likes to recall Ward's (1973) suggestion that, "...there may be a possibility for the efferent action of monaural stimulstion on the periphery of the contralateral auditory system in 'perstimulatory adaptation' ".

the above discussion clearly reveals that X_b (SDLB) > X_b (MH) is due to 'binaural interaction as correctly guessed by Ward (1973). Thus the process of 'binaural interacton' which was not well understood, perhaps, now appears to be clear. The 'binaural interaction' can be defined as the efferent action of monaural stimulation on the periphery of the contralateral auditory system. Here after, binaural interaction', refers to the above definition.

From the discussion,

Adaptation obtained at an adapting (X_b (at 60) in SDLB)
intensity of 60 dB SPL in SDLB

+* L_{tba} (at 60) -*L_{tbb} (at 60)
(Loudness efferent action)

(because loudness gain in the
comparision ear increases
perstimulatory adaptation)

adaptation measured at an inten-
sity higher tahn the adapting in- (X_b(at 60) in SDLB =
tensity of 60 dB SPL in SDLB
L_{thb} - L_{tha} -(*L_{thb} -*L_{tha})

L_{thb} - L_{tha}(because *L_{thb}- *L_{tha}=0,
during X_b measurements
the efferent action ceases

.'. X_h (at 60) in SDLB < X_b (at 60)
in SDLB.

[Therefore $\{L_{tbb}$ (at 60) - L_{tba}(at 60)
+ $*LL_{tba}$ (at 60) -$*L_{tbb}$ (at 60)$\}$
> L_{thb} - LL_{tha}]

In other words, in SDLB at 60 dB adapting stimulus X_h < X_b > 0 results becouse X_b (SDLB) will be greater due to the 'loudness gain' in the comparison ear(binaural interaction')whereas this loudness gain will be absent during X_h measurment (i.e., when

the post- adapted test tone is presented at an ibtensity higher then the adapting intensity, the efferent action ceases).

Regarding the question--why do we observe levelling off of adaptation above 60 dB SPL in SDLB technique? the answer can be obtained as follows:

avilable date: X_b (at 60 dB) in SDLB
= X_b (at 80 dB) in SDLB
= 20 dB (Weiler et al, 1972)

The data for MH technique at adapting intensity of 80 dB SPL is not available. However, it is reasonable to except, X_b (at 80)>0

as X_b (at 60) is know to be greater than 0 dB. The condition required for X_b (80) > 0 is a > -a'. This condition can be expectad in the adapting ear during post-adapted balnces in SDLB method. Therefore in the adapting ear, L_{tba} (at 80)< L_{tbb}(at 80) can be expected.

In the comparison ear, two conditions will prevail during the post adapted balance: (1) the conditions due to 'binaural interaction' and (2) the conditions due to adaptation of the comparison ear through cross-over of the adapting

Due to the condition (1), *L_{tbb} (at 80) < *L_{tba} (at 80) can be wxpected in the comparison ear. (.'. X_b < 0 or *a < *-a'). Due to the condition (2),*L_{tbb} (at 80) = *L_{tba} (at 80) can be expected in the comparison ear (.'. at adapting intensity of 80-IA = 40 dB SPl, *Xb (at 80-IA) = 0, *a (at 80-IA) = *-a' (at 80 - IA) can be expected as per the data reported by Glass & Weiler (1979). The combined effects of tha two condition in the comparison ear would be: *L_{tba} (at 80) > *L_{tbb} (at 80) i.e., The loudness of the post-adapted test tone in the comparison ear will be louder then the pre adapted test tone of the comparison ear at 80 dB SPL. How, comparison the situations prevailing in the adapting ear and the comparison ear, together. L_{tbb} (at 80) > L_{tba} (at 80) (stuation in the adapting

*L_{tbb}(at 80)< *L_{tba} (at 80) (situation in the comparison ear)

adaptation obtained at an
asapting intensity of 80
dB SPL in SDLB. (X_b (80) in SDLB) -
L_{tbb}(at 80) - L_{tba} (at 80)
+*$_{Ltb}$(at 80) -*L_{tbb}(at 80)

(.'. Loudness gain in the comparison ear incresses 'perstimulatory adaptation').

Adaptation obtained at an
adaptation intensity of dB
SPL in SDLB

(X_b (60) in SDLB)
L^{tbb} (at 60) - L_{tba} (at 60)
+*L_{tba} (at 60) - *L_{tbb} (at 60)
(because Loudness gain in the
comparison ear increases
'per stimulatory adaptation')

The available data shows that:
X_b (at 80) in SDLB = X_b (at 60) in SDLB
.. L_{tbb} (at 80 - L_{tba} (at 80) + *L_{tba} (at 80)- *L_{tbb} (at 80)
- L_{tbb} (at 60) - L_{tba} (at 60) + *L_{tba} (at 60) - *L_{tbb} (at 60)

Rearranging.

L_{tbb} (at 80) - L_{tba} (at 80) - L_{tbb} (at 60) + L_{tba}(at 60)
= *L_{tba} (at 60) - *L_{tbb} (at 60)-*L_{tba} (at 80) +*L_{tbb}(at 80)

i.e., Loudness decrease in the adapting ear due to the increase in the intensity of the adapting stimulus (i.e., increase in intensity from 60 to 80 dB)

Loudness increase in the comparison ear due to the efferent action for 60 dB stimulus

\+ Loudness loss in the comparison ear due to the efferent action for 80 dB stimulus

Curiously, the above derivation shows that the efferent action at 80 dB SPL of the adapting stimulus is to reduce *the loudness of the post-adaptation test tone in the comparison ear and that the efferent action at 60 dB SPL of the adapting stimulus is to increase the loudness of the post-adapted test tone in the comparison ear.* Thus there exist two types of efferent systems. The efferent system which functions at low levels (≤ 60 dB) is concerned with "negative adaptation' and the efferent system which functions at high intensity levels is concerned with 'inhibition' i.e., arresting or inhibiting the sensory inputs from firing impulses. Since the efferent system which is responsible for 'negative adaptation' has already been identified as the efferent system innervating the outer hair cells ("of. pp.125-128") *the efferent system which brings about 'inhibition' (preventing the sensory units from firing) must be the efferent system which innervates the inner hair cells)*. The reason being that this efferent action is present only at high adapting intensity. It is known that the inner hair cells respond to high intensity sounds only. From the above discussion it is clear *that (+a') units originate from the action of the efferent system innervating the inner hair cells.*

Therefore, the increase in the adaptation, in the adapting ear, resulting from the increase in the intensity of the adapting stimulus (i.e., raising the internality from 60 to 80 dB) will be '*eclipsed*' by 'binaural iinteractions' in SDLB method.

Interestingly, the effects of 'binaural interaction' for 60 dB aad 80 dB adapting stimulus are different. When the adapting intensity is 60 dB SPL (or less), the efferent system innervating the outer hair cells will be responsible for the increase in the loudness of the post-adapted test tone in the comparison ear. When the adapting intensity is 80 dB SPL or more the efferent system innervating the inner hair cells will be responsible for the decrese in loudness of the post-adapted test tone in the comparison ear. Since the two efferent systems operate togetter when the adapting stimulus is at 80 dB SPL, the net result will be that the loudness of the post-adapted test tone in the comparison ear will be almost equal to the loudness of the pre-adapted test tone in the comparison ear or pre-adapted test tone in the adapting ear). Consequently $*L_{tbb}$(at 80 dB) = $*L_{tba}$(at 80) =

L_{tbb} (at 80). Finally, X_b(at 80) in SDLB= L_{tbb}(at 80)-L_{tba} (at 80)=20;

X_b(at 60) in SDLB = L_{tbb}(at 60)-L_{tba}(at60)+ $*L_{tba}$ (at 60) - $*L_{tbb}$ (at 60)=20

In sum, it can be stated that the levelling off of adaptation observed in SDLB method, is mainly due to the 'binaural interaction'. At $\leq$ 60 dB SPL of the adapting stimulus 'Binaural Interaction' will be due to the efferent system innervating the outer hair cells, whereas at 80 dB SPL of the adapting stimulus there will be a combined action of the two efferent systema in the comparison ear. The combined aotions of the two efferent systems are mainly responsible for the levelling off of adaptation observed in SDLB method.

Regarding the question--Why do we deserve $X_h < X_b > 0$ when the adapting intensity is about 80 dB SPL in SDLB method-the answer can be found on these lines:

In the adapting ear, $X_h < X_b > 0$ can be expected as MH technique should yield. tbe result: $X_h < X_b > 0$ when the adapting intensity is 80 dB SP (since the previous discussion revealed that at 80 dB SPL, the efferent system innervating the inner hair cells will be operating). The deductions from the data of the present study suggest that: $X_h < X_b > 0$ can be expected at very high adapting intensity if ORMLA technique is used. Since MH technique yields more positive adaptation at low adapting intensities, it is reasonable to expext $X_h < X_b > 0$ at a relatively lower adapting intensity for MH technique. As mentioned earlier, ORMLA and MH techniques measure 'residual' and 'concomitant' adaptation respectively. The difference in the amounts of adaptation observed between MH and ORMLA techniques, is mainly due to 'concomitant' and 'residual' nature of adaptation measurments involved in the two techniquees.

With the above clarification, $X_h < X_b > 0$ can be expected in the adapting ear when the adapting intenaity is about 80 dB SPL. As per the deductions from the present data, the necessary conditions are: $a < a + a' > 0$; (i) $a' > 0$, (ii) $a > -a'$ & (iii) $a > 0$. Therefore, $L_{tbb} - L_{tba} > 0$

and $L_{thb} - L_{tha} > 0$ can be expected in the <u>adapting ear.</u> Since X_h depends on (a) units and X_b depends on (a),(+a') and (-a') units, $X_h < X_b$. (however the relative contrlibution of (-a') units will be insignificant).

In the comparison ear,

$*L_{tbb} = *L_{tba}$ can be expected. Earlier it was discussed that at adapting intensity of 80 dB SPD, both the efferent systems would be operating togethar and hence $*L_{tbb} = *L_{tba}$ in the comparison ear ("of. pp. 137-140").

Due to the adaptation of the comparison ear through cross-over of the adapting stimulus $*L_{tbb} = *L_{tba}$ can be expected ($*X_b = *X_{b-40} = 0$ can be expected--this in similar to $X_h = X_b = 0$, where b-40 refers to adapting intensity (80) -IA(40), When the adapting intensity is b-40, *a at(b-40) = *a at(b-40) + *a' at(b-40) = 0 can be expected. MH technique at 40 dB SPL (80-40) adapting intensity, can be expected to yield 0 dB adaptation vide: data reported by Glass & Weiler, 1979).

$*L_{thb} - *L_{tha} = 0$ (.'. the efferent actions will cease the moment the post adapted test tone at an intensity higher than the adapting intensity is presented in the adapting ear-- the efferent actions will cease in both the cars).

or $*X_h = 0$

Due to the adaptation of the comparison ear through the cross-over of the adapting stimulus, $*L_{thb} = *L_{tha}$ (because a* at (b- 40)= 0).

Summing up the above situations prevailing in the two ears during post adapted balance.

X_b in SDLB = $X_b - *X_b = X_b$ (because $*X_b$ =0)
X_h in SDLB = $X_h - *X_h = X_h$ (because $*X_h$ =0)
X_h in SDLB < X_b in SDLB (because X_b in SDLB = X_b

X_h in SDLB = X_h

X_b dependes on (a)&(a')
X_h depends on (a) only)

Thus $X_h < X_b > 0$ is observed in SDLB when the adapting intensity is 80 dB SPL.

The combined efferent actions in the comparison ear and the adapting ear, together with the cessation of efferent actions duriong X_h measurements, are responsible foe $X_h < X_b > 0$, in SDLB method at 80 dB SPL.

Morgan and Davis (1973) have reported that SDLB (heterophonic) technique does not show adaptation for 500 Hz tone at 70 dB SPL for 12-min adapting period. This results shows that 'binsural interaction' is effective only when the adapting stimulus and the comparison stimulus are of the same frequency.

All the above disoussions clearly revealed the mechanism of 'perstimulatory adaptation'. Thus, the deductions from the data of the present study are very useful in understanding the loudness coding during auditory adaptation. The mechanisms involved in 'perstimulatory adaptation' and, the controversies prevailed in the area of auditory adaptation are satisfactorily answered by the data of the present study.

The fact that the efferent action (negative adaptation) persists even after the withdrawal of the adapting stimulus (see for example $X_h > X_b < 0$) is probably an important 'clue' for the mechanism of 'tinnitus'. The pathophysiology of tinnitus is yet to be know The discovery that the efferent action negative adaptation) activies the sensory inputs even in the absence of acoustic stimulus is a clear evidence for understanding the patho-physiology of tinnitus.

In the light of the results of the present study it may be hypothesized that a disturbance in the efferent system innervating the outer hair cells, may be responsible for 'tinnitus' observed in, stleast some pathological cases.

Tinnitus, arising after exposure to continuous auditory stimulation, is likely to be due to the action of the efferent system innervating the outer hair cells.

Having known the soures of 'a' +a' and -a' units and also the possible mechanisms of loudness coding during auditory adaptation, it may be possible to visualize the adaptation process in the different results observed in the present study.

(1) $X_h > X_b < 0$; $a > a + a' < 0$

The necessary coditions for this result are:

(i) $a' < 0$ & (ii) $a < -a'$

This result was observed when the adapting stimulus (1 KHz) was presented at 110 dB SPL for 7-min. X_h was measured at 120 dB SPL, (see experiment VIII a).

L_{tbb} = loudness contributed by 'Simple category'

L_{tba}=loudness contributed by 'simple category'

- loudness contributed by stable adaptable neural units (a).

+ loudness contributed by (-a') units 'contribution of NI0H units through the action of the efferentt system innervating the outer hair cells)

L_{thb} = loudness contributed by 'simple Category'

+ loudness contributed by additional units ('.' 120 dB > 110 dB).

L_{tba} = loudness contributed by 'simaple Category'

+ loudness contributed by the additional units

- loudness contributed by the stable adapted neural units (a).

The above description shows that:

(i) $L_{tba} > L_{tbb}$.'. X_b is negative $(a < -a')$

(ii) $L_{tha} < L_{thb}$.'. $X_h > 0$

(2) $X_h X_b = 0$

L_{tbb} = loudness contributed by 'simple Category'

L_{tba} = loudness contributed by 'simple Category'

- loudness contributed by (a) units (stable adaptable)

+ loudness contributed by (-a') uunits (contribution of NIOH units through the efferent action)

L_{thb} = loudness contributed by 'simple Category'

+ loudness contributed ty the additional units

('.' $120 > 110$)

L_{tha} = loudness contributed by 'simple category'

+ loudness contributed by the additional units

- loudness contributed by (a) units

The above description shows that:

(i) $L_{tba} = L_{tbb}$ ('.' $a = -a'$)
.'. $X_b = 0$
(ii) $L_{tha} < L_{thb}$ (because of the presence of (a) units)
.'.$X_h>0$

(3)$X_h > X_b > 0$; $a > a=a' > 0$

The necessary condition are: (i) $a'< 0$ (ii) $a > -a'$

(iii) $a > o$

L_{tbb} = loudness contributed by 'simple Category'

L_{tba} = loudness contributed by 'Simple Category'

- loudness contributed by a stable adaptable neural units (a) + loudness contributed by (-a') units (loudness contributed by the action of the efferent system innervating the outer hair cells).

L_{thb}- = loudness contributed by 'sim1ple category' + loudness contributed by the additional units.

L_{tha} = loudness contributed by 'simple category' + loudness contributed by the additional units - loudness contributed by the stable adaptable neural units(a).

the above description shows that:

(i) $L_{tba} < L_{tbb}$ ('.' $a > -a'$> .'. $X_b > 0$

(ii) $L_{tha} < L_{thb}$ (because of the presence of (a) units)

.'. $X_h > 0$ and $X_h > X_b$ ('.' $a > -a'$)

(4) $X_h = X_b = 0$; $a = a + a' = 0$

The necessary conditions are:

(i) $a' = 0$ (ii) $a = -a' = 0$

L_{tbb} = Loudness contributed by 'Simple Category'

L_{tba} = Loudness contributed by 'simple Category'

This result was not observad in any subject as it is obvious that after adapting the ear using 110 dB SPL stimulus (1 KHz) for 7-min, a = 0 is highly impossible.

(5) $X_h < X_b = 0$; $a < a + a' = 0$

The necessary conditions are:

(i) $a' > 0$ (ii) $a = -a'$

The result was also not obasrved is any subject. It is obvious that the necessary condition cannot be satisfied. $a' > 0$ can be expected at very high adapting intensity, whereas $a = -a'$ can be expected at moderate intensity of the adapting stimulus. The co-existence of these two necessary conditions is impossible.

(6) $X_h < X_b > 0$; $a < a + a' > 0$

The necessary conditions are:

(i) $a' > 0$ (ii) $a > -a'$ (iii) $a > 0$

L_{tbb} = Loudness contributed by 'Simple category'

+ Loudness contributed by neural units innervating the inner hair cells.

L_{tba} = Loudness contributed by 'simple category' + Loudness contributed by neural units inner hair cells.

- Loudness contributed by positive unstable adapted neural units (the number of activated NIIH units which cease functioning due to the action of the efferent system innervating the inner hair cells)

+ Loudness contributed by -a' units (this is insignificant).

L_{thb} = Loudness contributed by simple category' + Loudness contributed by NIIH + Loudness contributed by additional units ('.' 130 > 120).

L_{tha} = Loudness contributed by 'simple category'

+ Loudness contributed by NIIH

+ Loudness contributed by additional units

- Loudness contributed by stable adaptable neural units (a).

The above sedcription shoes that:

(i) $L_{tba} < L_{tbb}$ ('.' Loudness loss due to {a) and
+a units is more than the loud-
.'. $X_b > 0$ ness gsin due to -a' units, which
is insignificant here).

(ii) L_{tha} L_{thb} (becouse of the presence of (a) units)
.'.$X_h > 0$

But $X_h < X_b$ ('.' X_b is determined by (a) and +a' units. whereas, X_h is detemined by (a) units only. Also when the post adapted test tone is presented at an intensity higher then the adapting intensity, the efferent action ceases).

Thus all the obtained results can be vieualised.

CHAPTERVI

A REVISED MODEL FOR LOUNDESS CODING DURING AUDITORY ADAPTATION

The results of the present study and the controversies prevailing in the area of auditory adaptation (including the mechanisms involved is perstimulatory adaptation), cannot be explained on the basis of the existing models for loudness coding during auditory adaptation. An adequate model which resolves the prevailing controversies and also which provides satisfactory explanation to the data obtained in the present study, seems to be the outcome of the present investigation. The essence of the revised model for loudness coding during auditory adaptation is presented in the following steps:

1. The adapted neural units are of three types: (1) stable adapted neural units (a) (11) Positive unstable adapted neural units (+a') (iii) Negative unstable adapted neural units (-a').

2. 'Simple Category' and 'Complex Category' (terms used by Frishkopf and Goldstein) may be the sources for (a) units i.e., (a) units criginate from the place of maximum stimulation of the basilar membrane (a) units for low frequencies originate from 'complex category' and (a) units for $\geq$ 1 KHz originate from 'simple category'.

3. The source of +a units is the Neural Units Innervating the inner Hair Cells (NIIH) and they are produced by the action of the efferent system innervating the inner hair cells.

4. The source of -a' units is the Neural units innervating the Outer Hair cells (NIOH) and they are produced by the action of the efferent system innervating the outer hair cells.

5. -a' units perform a reverse function of +a' units and also that of (a) units. In other cwords, - a' units (responsible for negative adaptation)will be contributing to the loudness during the adaptation process. +a' and -a' units may be linked to 'R_2' and 'R_1' processes (respectively) reported by Hirsh and Bilger(ward 1963) connection with 'bonuce' phenomenon observed within 2-min of recovery time during TTS experiments, Thus the revised model corroborates Hirsh and Bilger's hypothesis that 'bounce' phenomenon is a neural phenomenon.

6. +a' and -a' units regain their original preadapted state whenever a test tone at an intensity higher than the adapting intensity is presented during the post-adapted state. In other words, the moment the post-adapted test tone at an intensity higher than the adapting intensity is presented, the efferent action ceases.

7. For high stimulus intensities, loudnes of the post adapted test tone at the adapting intensity is determined by the total number of activated neural units from the following: (i) 'simple category' or'complex category' (ii) NIIH and (iii) NIOH. However, the contribution of the sensory units (activated by the action of the efferest system innervating the outer hair cells) for loudness of the post adapted test tone will be insignificant.

8. For low or moderate intensity stimulus, the loudness of the post adapted test tone at adapting intensity.

is determined by 'simple category' (or complex category) and NIOH (sensory units of outer hair cells activated by the action of the efferent system innervating the outer hair cells).

9. Possible mechanisms of loudness adaptation. When a stimulus ($\geq$ 1 KHz) of moderate intensity is continuously presented to one of the ears of a normal hearing subject, the adaptation process (i.e., a gradual and continuous decrease in the number of activated neural units) begins in the 'simple category'. This process goes on as long as the adapting stimulus is continued; hence, stable adapted neural units (a) will be increasing. Simultaneously with the adaptation process, the number of sansory units innervating the outer hair cells, (NIOH) activated by the efferent system (innervating the outer hair cells) gradually increses as long as the adapting stimulus is continued i.e., -a' units will be increasing. This process is known as 'negative adaptation' (or reverse adaptation). As the adapting stimulus is continued, more and more number of sensory units innervating the outer hair cells (NIOH) begin to fire nerve impulses. initially, the rate of decrease in the number of activated neural units in the'simple category' will be faster than the rate of increase in the number of activated (through the efferent action) sensory units innervating the outer hair cells. After some time, the rate of increase in the activated sensory units innervating the outer hair cells will catch-up' with the rate of decrease in the number of activated units of the 'simple category'. As a consequence of this, the total number of nerve impulses contributing to the loudness of the adapting stimulus (or test tone at the

adapting intensity) remains fairly constant (contribution of the nerve impulses from the 'simple category' will be decreasing, but the contribution of nerve impulses from the NIOH will be **increasing**). This way asymptotic loudness adaptation can be explained.

Incidentally, the above description, reveals a 'vital' information about 'inhibition' process. 'Inhibition' process in the auditory system is poorly understood. The revised model appears to be a 'break-through' in paycho-acoustic and electro-physiological research as far as understanding the mechanisms of 'inhibition' process in the auditory systems is concerned, Since -a' units are responsible for inhibiting the adaptation process, phenomenon of negative adaptation can be viewed as 'inhibition process'. As explained in Chapter V (pp 125-128), the efferent system innervating the outer hair cells, is responsible for -a' units. Since the efferent system is known for its 'inhibitory' function, the negative adaption brought about by the efferent system (innervating the outer hair cells) may be regarded as 'inhibition of adaptation process.

10. X_h depends on (a) units only (see pp 123-124 for its derivation).

11. X_b depends on a , +a' and -a' (see pp 122-123 for its derivation).

12. X_l depends on a_l + a_l' and -a_l' (see pp 124-125 for its derivation)

13. The effect of (a) units can either be enhanced by +a' units aad/or decreased or cancelled by -a' units. In other words, the loudness loss brought about by (a) units can be aggravated by +a' units and/or the loudness can be minimized or completely cancelled or loudness can be increased by the action of -a' units.

14. The revised model can b#e used to explain the different results obtained in the present study:

(a) $X_h > X_b < 0$; $a > a + a' < 0$

The necessary canditions are : (i) $a' < 0$ and (ii) $a < -a'$ (se pp.125-128 for the discussion)

(b) $X_h > X_b = 0$

$a > a + a' = 0$

The necessary conditions are : (i) $a' < 0$ and (ii) $a = -a'$ (see pp.129-147 for the discussion)

(c) $X_h > X_b > 0$

$a > a + a' > 0$

The necessary conditions are: (i) $a' < 0$ (ii) $a > a'$ (iii) $a > 0$

(see pp 147-148 for the discussion)

(d) $X_h = X_b = 0$

$a = a + a' = 0$

The necessry conditions are; (i) $a' = 0$

(ii) $a = -a'$

(iii) $-a' = 0$

(Note: This result was not observed) (See pp: 148 for explanation)

(e) $X_h < X_b = 0$

$a < a + a' = 0$

The necessary conditions are: (i) $a' > 0$

(ii) $a = -a'$

Note: This result was also not observed is any subject (See pp. 149 for explanation)

(f) $X_h < X_b > 0$

$a < a + a' > 0$

The necessary coditions are; (i) $a' > 0$

(ii) $a > -a'$

(iii) $a > 0$

(See pp.149-150 for the discussion)

(g) $X_l < X_b > 0$

a_l) $a_l' < a + a' > 0$

The necessary conditions are: (i) $a_l + a_l' < a + a'$ and (ii) $a > -a'$ (See pp. 131 for the discussion)

15. X_b (SDLB) > X_b (MH) is due to "binaural interaction'. The 'binaural interaction' can be defined as the efferent action of monaural stimulation on the periphery of the contralateral auditory system (See pp.133-136 for a thorough discussion).

16. X_b (at 60 dB) in SDIB = X_b (at 80 dB) in SDLB = 20 dB (the data reported by Weiler et al, 1972), is due to a phenomenon which may be nemed--the '<u>eclipses phenomenon'</u>.

The "eclipse phenomenon" is the phenomenon in which the increase in the amount of adaption which should result in the adapting ear, due to the increase in the intensity of the adapting stimulius (i.e., increasing the intensity from 60 dB to 80 dB SPL) is 'eclipsed' by the combined actions of the two efferent systems (the efferent system innervating the outer hair cells and the efferent system innervating the inner hair cells) in the comparison ear. The action of the efferent system innervating the outer hair cells is to increase the loudness of the post adapted test tone in the comparison ear and the action of the efferent system innervating the inner hair cells is to decrease the loudness of the post adapted test tone in the comparison ear. when the adapting stimulus is at 80 dB SPL in the adapting ear, there will be a combined action of the efferent systems in the comparison ear which results in $*L_{tba} = *L_{tbb} = L_{tbb}$ (see pp 137-141 for & thorough discussion).

17. $X_h < X_b > 0$ at 60 dB SPL adapting intensity in SDLB, is due to the fact that X_b will be greater as a result of 'loudness gain' in the comparison ear (binaural interaction), whereas this 'loudness gain' will be absent during X_h measurements (when the post adapted test tone is presented at an intensity higher than the adapting intensity the efferent action oeases) (See pp. 134-137 for a thorough discussion).

18. $X_h < X_b > 0$ at 80 dB SPL adapting intensity in SDLB, is due to the combined efferent actions in the comparison ear and the adapting ear, together with the cessation of efferent actions during X_h measurements (see pp 142-144 for a thorough discussion).

19. 'Binaural Interaction' is effective only when the adapting stimulus and the comparison stimulus are of the sane frequency. In support of this, the data reported by Morgan and Davis (1973) can be recalled.(They found that 500 Hz tone at 70 dB SPL for 12-min did not show adaptation for SDLB (hetereophonic) technique)

20. The fact that tha efferent action (negative adaptation) persists even after the withdrawal of the adapting stimulus (See for example: $X_h > X_b < 0$ PP.125-128) is probably an important clue to the mechanism of 'tinnitus'. The pathophysiology of tinnitus is yet to be known. The discovery that the efferant action (action of the efferent system innervating the outer hair cells) activates the sensory inputs even in the absencec of the acoustic stimulus is a clear evidence for understanding the patbophysiology of tinnitus. tinnitus, arising out of exposure to continuous auditory stimulation is likely to be due to the action of the efferent system innervating the outer hair cells. A disturbance in the efferent system innervating the outer hair cells, may be responsible for the 'tinnitus' observed in, atleast,some pathological cases.

CHAPTER VII

SUMMARY AND CONCLUSION

A relation between loudness and acoustic reflex response exists if signals especially 0.5 KHz and 1 KHz are equated in terms of the magnitude of the middle ear muscle response. In the light of the evidences provided by many investigators, including the author (Thomsen, 1955; Ewertson et al. 1958; Flottorp et al 1971; Block and Wrightman, 1977; Block and Wiley, 1977; Gorga, Lilly and Length, 1980) regarding the existence of the relationship between loudness and acoustic reflex, it was reasonably assumed that a relationship does exist between loudness and acoustic reflex response in normal hearing subjects. Additionally, Borg and Odman have (1979) confirmed that decay and recovery originate in the afferent auditory system and not in the acoustic reflex muscles.

A new objective technique viz., objective Residual Monaural Loudness Adaptation (ORMLA) was developed (Vyasamurthy, 1977) for measuring adaptation. This technique satisfies most of the criteria prescribed by small (1963) for the measurement of 'adequate' adaptation.

The thesis deals with adaptation measurment made using the new technique. The resulting data led the investigator to develop a revised model for loudness coding during auditory adaptation. The review model provides answers to many of the controversies prevailing in the area of auditory adaptation-and also the revised model appears to be a break-through in auditory physiology.

The subjects participating in the different experiments consisted of 32 to 48 normally hearing ($\leq$ 20 dB HL ANSI 1969) students belonging to the All india institute of speech and Hearing, Mysore-570 006, and to the neighbouring colleges, ranging in age from 19 to 27 Years. The adapting stimulus was always presented to the left ear and monitoring of the reflex response was done in the right ear (air-pressure in the right ear canal was set at Omniwater). The changes in the magnitude of reflex response (stiffness changes of the middle-ear system) as indicated by the deflection of the Balance Meter (BM) needle of a calibrated electro-acoustic impedance bridge - Madsen 20-73 were noted down at different intensities of the test tone before adapting the ear, Consistant 'BM reading' at different intensity levels of the test tone were noted. The inter-stimulus interval was 30 sec for test tones < 100 dB SPL and 60 sec for test tones $\geq$ 100 dB SPL. The duration of each presentation of the test tone was 1.5 sec. After noting down the 'BM reading' for the test tone at different intensity levels, the probe tone (220 Hz) in the probe ear (right ear) was put off. Then, the adapting stimulus was presented continusly (duration, intensity and frequency of the adapting stimulus varied depending on the type of experiment). At the end of the required duration of exposure of the adapting stimulus, the adapting stimulus was withdrawn and after 5-sec rest period (this rest period was required for setting the knobs) the test tone at a level depending on the type of experiment was presented for 1.5 sec. The 'BM readings' was noted. This reading was compared with the 'BM readings' of the pre-adapted test tons levels, the pre-adapted test tone level, which had produced the same 'BM reading' (magnitude of reflex) as that of the post adapted test tone,was identified. Adaptation (in dB) was the difference between the post adapted test tone level and the pre-adapted test tone level which produced the same 'BM readings' (magnitude of reflex) as that of the post adaptad test tone. This way), loudness adaptation was measured in decibels (dB) objectively, loudness adaptation measured in the above manner has been termed 'Objective Residual Monaural Loudness Adaptation' (ORMLA).

'BM readings' for pre-adapted test tone levels were recorded prior to each adaptation test. A minimum of 24 to 48 hrs rest, between adaptation tests, was allowed for each subject to ensure complete recovery from the fatigue processes.

The procedure for finding the recovery time from adaptation was exactly the same as the procedure used for measuring adaptation, but with a little difference. The measurement of adaptation did not stop at a single presentation of the test tone, (for 1.5 sec) 5 sec after the withdrawal of the adapting stimulus. The test tone was repeatedly presented once in 60 sce for 1.5 sec and each time the 'BM reading' was noted. This procedure was continued until the magnitude of reflex (BM reading) was the same as the 'BM reading' produced by the test tone during pre-adapted condition. the 'BM reading' obtained at 60 sec intervals were compared with the 'BM reading' which were recorded during pre-adapted condition to complete adaptation (in dB) at 60 sec intervals of recovery time.

Several experiments were carried out. The results of these experiments led the investigator to propose a revised model for loudness coding during auditory adaptation. The following conclusions have been made:

1. For pure tones viz., 0.5 and 1 KHz, the magnitude of reflex (BM reading) can be used as a 'measure' of loudness perceived by the normal hearing subjects.
2. (the 'BM readings' at different intensity levels of a test tone remained the same after 7-min of silent interval—indicating that the ORMLA technique could be used reliably without much interference from the possible variables.

3. The null hypothesis that the duration of exposure has no significant effect on the amount of adaptation was rejected(p<0.01)for duration below 7-min and the null hypothesis that the duration of exposure has no significant effect on the amount of adaptation was accepted (p>0.05)for duration $\geq$ 7 min. Thus the results showed that asymtotic loudness adaptation reached by 7-min.

4. The null hypothesis that the frequency of the adapting stimulus has no significant effect on the amount of adapting warn rejected (p<0.001)

5. The null hypothesis that the frequency of the test tone has no significant effect on the amount of adaptation was rejected (p<0.0003). Thus the results showed that the test frequencies do influence tbe amcunt of adaptation measured. Also, the results showed that adaptations does spread to the neighbouring frequencies (More adaptation was observed at the a adating frequency).

6. The effect of frequency of the adapting stimulus on the amount of adaptation was negligible when the adapting tones (0.5, 1 and 2 KHz) were of equal loudness levels.

7. The null hypothesis that the intensity of the adapting stimulus has no significant effect on the amount of adaptation was rejected ($p \leq 0.001$).

8. The null hypothesis that there is no significant difference between the X_L values obtained in the two conditions: (A) adapting the ear useing 1 KHz tone at 105 dB SPL for 7 min and measuring the adaptation using 1 KHz tone at 100 dB SPL, (B) adapting the ear using 1 KHz tone at 115 dB SPL for 7-min and measuring

adaptation using KHz tone at 100 dB SPL, was accepted ($x^2 = 0.5$; df = 1, $P > 0.5$). Thus the results confirmed Small's (1963) prediction.

9. The null hypothesis that there is noe significant difference between X_b and X_L values, was rejected ($x^2 = 26.95$; df = 1; $P < 0.001$). Mean X_b was 7.96 (S.D = 3.38) and Mean X_L was 4.28 (S.D = 3.08). Thus the results ($X_b > X_L$) confirmed Small's prediction (1963).

10. The null hypothesis that there is no significant difference between X_h and X_b values, was rejected ($x^2 = 8.29$; df = 1; $P \leq 0.001$). interestingly, inter-subject variability in the results was observed. Ninenteen out of 43 subjects tested, showed; $X_h > X_b > 0$; thirteen subjects showed; $X_h = X_b > 0$; four subjects showced; $X_h < X_b > 0$ and seven subjects showed $X_h > X_b <= 0$. Thus the results were not in agreement with Small's hypothesis (1963). (adapting intensity = 110 dB S

11. Repeated testing on a single subject (the investigator) showed: $X_h > X_b > 0$ consistently. (adapting sntensity=110dB SPL)

12. At very high adapting intensity (120 dB SPL for 7-min) 5 adult subjects showed: $X_h < X_b > 0$. On retesting, the same results were obtained. Thus Small's prediction (1963) appeared to be true at very high adapting intensity.

13. Repeated testing on the single subject (the investigator) at very high adapting intensity (125 dB SPL for 7-min) showed: $X_h < X_b > 0$ consistently. Thus Small's prediction (1963) appeared to be true at very high adapting intensity.

14. when 0.5 KHz tone at 115 dB SPL for 3-min was used as the adapting stimulus, average amount of adaptation obtained was 3.52 dB (S.D = 2.97). 50% of the subjects (16) showed complete recovery from adaptation within a minute. The maximum recovery time was 3 min. This normative data for recovery time might be useful if a diagnostic test, based on recovery time for datecting retro-cochlear pathology cases, would prove to be feasible.

13. the time required for complete recovery was found to be dependent on the frequency of the adapting stimalus, The recovery time for 500 Hz tone was more rapid than the recovery time for 1000 Hz tone.

16. Like X_L the recovery time determined at an intensity lower than the adapting intensity was also reduced; hence, this finding supported Small's prediction (1963) with respect to recovery time also.

17. Test-retest data of the majority of the experiments showed very high correlation (significant at 1% level of confidence, except in one experiment in which correlation was sigbificant at 5% level of confidence).

18. The results of the present study led the investigator to propose a revised model for loudness coding during auditory adaptation the essence of the revised model are given in the following steps:

    (a) The adapted neural units are of three types: (1) Stable adapted nearal units (a) (2) Positive unstable adapted neural units (+a') and (3) Negative unstable adapted neural units(-a')

(b) 'simple category' and 'complex category' (terms used by Frlshkopf and Goldstein) may be the sources for (a) units i.e., (a) units originate from the place of maximum stimulation of the basilar membrane (a) units for low frequencies originate from 'complex category' and (a) units for $\geq$ 1KHz originate from 'simple category'.

(c) The source of (+a') units is the Neural Units Innervating the Inner Hair cells (NIIH) and they are produced by the action of the efferent system innervating the inner hair cells.

(d) The source of (-a') unite is the Neural Units Innervating the Cuter Hair cells (NIOH) and they are produced by the action of the efferent system innervating the outer hair cells.

(e) (-a') units perform a reverse function of (+a') units and also that of (a) units. In other words, (-a') units (responsible for negative adaptation) will be contributing to the loudness during the adaptation process. (+a') and (-a') units may be linked to 'R_2' and 'R_1' processes (respectively) reported by Hirsh and Bilger (word 1963)in connection with 'bounce' phenomenon observed within 2-min of recovery time during TTS experiments. Thus the revised model corroborates Hirah and Bilger's hypothesis that 'bounce' phenomenon is a neural phenomenon.

(f) (+a') and (-a') units regain their original pre-adapted state whenever a test tone at an intensity higher than the adapting intensity is presented during the post-adapted period. In other words, the moment the post-adapted test tone at an intensity higher than the adapting intensity is presented, the efferent action ceases.

(g) For high stimulus intensities, loudness of the post-adapted test tone at the adapting intensity, is determined by the total number of activated neural units from the following: (i)'simple category' or 'complex category' (ii) NIIH and (iii) NIOH. However, the contribution of the sensory units (activated by the action of the efferent system innervating the outer hair cells) for loudness of the post adapted test tone will be insignificant.

(h) For low or moderate intensity stimulus the loudness of the post adapted test tone at adapting intensity (Ltba) is determined by 'Sirmple Category' (or complex category) and NIOH (Sensory units of outer hair cells activated by the action of the efferent system innervating the outer hair cells).

(1) Asymptotic loudness adaptation results when the rate of increase in (a) and/or (+a') units becomes equal to the rate of increase in (-a') units.

(j) X_b depends on (a), (+a') and (-a') units.

(K) X_h depends on (a) units only.

(l) X_L depends on (a_L), (+a_L') and (-a_L').

(m) The effect of (a) units can either be enhanced by (+a') units and/or decreased or cancelled by (-a')units. In other words, the loudness loss brought about by (a) unite can be aggravated by (+a) units and/or the loudness loss can be minimized or completely cancelled or loudness cam be increased by the action of (-a') units.

19. X_b (SDLB) > X_b (MH) is due to 'binaural interaction'. 'Binaural interaction' can be defined as the efferent motion of the monaural stimulation on the periphery of the contralateral auditory system.

20. X_b (at 60) in SDLB = X_b (at 80) in SDLB = 20 dB,(the date reported by Weiler et al (1972) is due to a phenomenon named--the 'ecli[se pheomenon'.

21. X_h < X_b > 0 at 60 dB SBL adapting intensity in SDLB is due to: (1) Loudness gain ('binaural interaction') in the comparison ear while doing X_b measurement and (ii) the absence of this 'loudness gain' while doing X_h measurement.

22. X_h < X_b > 0 at 80 dB SPL adapting intensity in SDLB, is due to the combined efferent actions in the comparison ear and the adapting ear, together with the cessation of efferent actions during X_h measurments.

23. Binaural interaction' is effective only when the adapting stimulus and the comparison stimulus are of the same frequency.

24. The fact that the efferent action (negative adaptation) persists even after the withdrawal of the adapting stimulus, is probably an important clue to the mechanism of 'tinnitus. Tinnitus, arising out of exposure to continueus auditory stimulation is likely to be due to the motion of the efferent system innervating the outer hair cells. A disturbance in the efferent systam innervating the outer hair cells may be responsible for the 'tinnitus' obesrved in, at least, some pathological casses.

Recommendations

1. To substantiate the findings of the present study, X_b and X_h values may be determined for MH technique using adapting intensity of greater them 80 dB SPL.

2. A detailed study on 'negative adaptation' on normal and clinical population would be worthwhile for establishing the feasibility of using ORMLA technique as a special test in clinical audiology for testing the integrity of 'Low threshold' mechanism. Additionally, this type of study may provide more information regarding the action of the efferent auditory nervous system innervating the outer hair cells.

3. Establishment of adequate data, for recovery from adaptation, on normal and clincal populations, using ORMLA technique, on the same lines of the experiment IXa, is recommended for the consideration of ORMLA technique as an objective test for identifying retrocochlear pathology cases.

4. Since the result: $X_h < X_b > 0$ observed in SDLB technique, at adapting intensity of 60 or 80 dB HL (ISO, 1964), must be due to the efferent action/s of monaural stimulation on the periphery of the contralateral auditory system, SDLB technique can be used as a test for checking the integrity of the efferent system/s.

5. Electro physiological research studies on animals may be focussed on the efferent auditory system innervating the outer hair cells especially when the auditory stimulus is presented continously The results of such investigation may give further evidence to the psycho-acoustically observed phenomenon of 'inhibition' (negative adaptation) which results due to the action of the efferent system innervating the outer hair cells.

6. The research studies pertaining to cochlear implants for the deaf children, may have to explore the implications of the findings of the present study regarding the functions of the efferent auditory systems. It appears that the efferent systems operate like AVC (Automatic Volume Control) circuits in hearing aids. At low adapting intensities, the efferent system innervating the outer hair cells, plays a significant role in increasing the loudness of the sound. At high adapting intensities, the efferent system innervating the inner hair cells, plays a significant role in inhibiting the efferent units (innervating the inner hair cells) from firing.

7. In general, the result of the present study may have implications in auditory physiology and 'Neoro-Sciences'; hence it is recommended that the investigators currently engaged in psycho-acoustic and electro-physiological research

studies may focus their attention more towords the functions of the efferent auditory systems.

8. It appears that there are individual differences as far as the adaptation process (including the efferent action) is concerned hence, exploration of the factors responsible for the individual differences viz., magnitude of efferent action: magnitude of efferent action associated with NIOH; magnitude of efferent action associated with NIIH; and adaptability of stable adaptable neural units may contribute to the advancement of diagnostic and rehabilitative audiology (including the medical sciences).

Limitations

1. The main limitation of the study, perhaps, is that the adaptation (ORMLA) could not be determined immediately after the termination of the adapting stimulus—adaptation could be measured only after 5-sec rest period.

2. The investigators who strongly believe that there is no one-to-one relationship between loudness and reflex may not like the idea of using the 'magnitude of reflex' as a criterion for loudness perceived by tha normal hearing subjects. (However, the investigator would like to stress the point that be has not equated tha magnitude of reflex with the

loudness perceived in a causual way. infact, the relationship between loudness and reflex magnitude, in normal hearing subjects, was established through an experiment (experiment - I) and also be has relied on the studied reported by Gorga et al (1980), Block and Wightman (1977) and Block and Willey,(1977). Above all, the results of the study heve clearly resolved the controversies which were prevailing in the area of auditory adaptation; hence, the objections (if there are any) for assuming a relationship between 'magnitude of reflex' and the loudness perceived, appear to be not reasonable).

3. The experiment I showed that the relationship between loudness perceived and the magnitude of reflex, appeared to be not true at 2 KHz. Hence, strictly speaking, ORMLA technique may not be suitable for measuring adaptation at 2 KHz. (Nevertheless, at 2 KHz, asymptotic loudness adaptation was observed. Thus, it may not be unreasonable to assume that ORMLA technique is useful for measuring adaptation at 2 KHz also.

4. During testing, motor activities such as vocalization, coughing, sneezing, laughing, yawning and frequent swallowing act as variables and hence they are required to be controlled for reliable results.

BIBLIOGRAPHY

American National Standards institute Specifications for audiometers ANSI53.6- 1969.American National standaeds institute,Inc.,NewYork.

Anderson, H., Barr, B., and Wedenberg, E., (1969). Intrasural reflexes in retrocochlear lesions. In Hamburger, c., and Wersall, J. (eds.), Disorders of the Skull Base Region. 10th Nobel Symposium. pp. 49-59 (Almquist and Wiksell, Stockholm).

Anderson, H., Barr B., and wedenberg, E (1970a). Early diagnosis of VIII nerve tumours by acoustic reflex tests. Acta. Oto-lar.. Suppl. 263, pp.232-237.

Anderson, H., Barr, B., Wadenberg, E. (1970b). The early detection of acoustic tumours by the atapedius reflex test. In Wolstenholme and Knight, Sensorineural Hearing Loss. pp. 274-289 (Churchill, London).

Beadle, R., and Harford, E.A. (1973). A oomparison of acoustic reflex and loudness growth in normal and pathologic ears. J. speech and Hearing Res. 16:271-281

Block, M.G., and Wightman, F.L. (1977). A statistically based measure of the acoustic reflex and its relation to stimulus loudness. J. Acoust. Soc. Am. 61:120-125.

Blook, M.G., and Wiley, T.L. (1977). Acoustic reflex characteristics and loudness. Natn. Conv. Am. Speech and Hearing Ass.

Borg, E., and Odman, B. (1979). Decay and recovery of the acoustic stapedius reflex in humans. Acta Oto-lar. 87:421-428.

Bray, D.A., Dirks, D.D., and Morgan, D.E. (1973). Perstimulatory loudness adaptation. J. Acoust. Soc. Am. 53: 1544-1548.

Cartwright, w,R., and Lilly, D.J., (1979). Adaptation of the acoustic reflex (in preparation) (as mentioned in Gorga et al (1980). Effect of signal bandwidth upon threshold of the acoustic reflex and upon loudness. Audiology 19: 277-292.

Cunningham, D. (1976). Admittance values associated with the acoustic reflex and reflex decay. J. Am. Aud. Soc. 1:197-205

Dallos, P. (1964). Dynamics of the acoustic reflex: Phenomanological aspects. J. Acoust. Soc. Am. 36: 2175-2183.

Davis, J.M., and weiler, E.M.(1978). Ear dominance effects in loudness following auditory adaptation. Brit. J. Audiol. 12 (2): 59-64.

Dirks, D.D., Morgan, D.E., and Bray, D.A., (1974). Perstimulatory loudness adaptation in selected cochlear impaired and masked normal listeners. J. Acoust.Soc. Am. 56: 554-561.

Djepesland, G., Flottorp, G., and Winther, F. (1967). Size and duration of acoustically elicited impedance changes in man. Acta. Oto-lar. Suppl.224:220-228.

Djupealand G., and Flottorp, G. (1970). Correlation between the Fowler loudness balance test, the Metz recruitment test, and the Flottorp-opheim aural harmonic test in various types of hearing impairment. Int.Audiol. 9: 156-175.

Egan, J.P. (1955). Perstimulatory fatigue as measured by haterophonic loudness balances. *J. Acoust. Soc.Am*. 27: 111-120.

Elliott, D.N., and Fraser, W. (1970). Fatigue and Adaptation. In J.V. Tobias (Ed.), *foundations of Modern auditory Theory* (Vol.1). pp. 115-155 (Academic Press, New York, London).

Ewertsen, H.W., Filling, S., Terkildsen, K., and Thomsen,K.A. (1958). Comparative recruitment testing. *Acta. Oto. Kar. Suppl*. 140: 116-122.

Fraser, W.D., Petty, J.W., and Elliott, D.N., (1970). Adaptation: Central or Peripheral? *J. Acoust. Soc. Am*. 47: 1010.

Givens, G.D., and Seidemann, M.P. (1979). A systematic investigation of measurement parameters of acoustic-reflex adaptation. *J. Speech Hear, Dis.,* : 534-542

G1ass, E.B., and Weiler, E.M. (1979). Monaural balances and loudness coding during auditory adaptation. *Brit. J. Audiol*. 13: 61-62.

Gorga, M.P., Lilly, D.J., and length, R.V., (1980). Effect of signal bandwidth upon threashold of the acoustic reflex and upon loudness. *Audiology*. 19:277-292.

Habener, S.A., and Synder, J.M. (1974). Stapedial reflex amplitude and decay in normal hearing ears. ,*Arch. Otolaryngol*.100: 294-297.

Hetu, R., and Careau, P. (1977). Decay of the acoustic reflex during steady-state and intermittent noise exposures. *J. Acoust. Soc. Am*. 61 553 (A).

Hood, J.P. (1950). Studies in auditory fatigue and adaptation. Acto Oto-lar Suppl.92.

Jepson, 0. (1963). Middle ear muscle reflexes in man. In J, Jerger (ed.) , M<u>adern Developments in Audiology.</u> pp. 193-239 (acadamtc Press, New York).

Jerger, J., Jerger, S., and Mauldin, L. (1972). Studies in Impedance auditory I. Normal and sensorineural loss. <u>Archs. Otolaryngol</u>. 96: 513-523.

Jerger, J., Harford, E, Clemis, J., and Alford, B. (1974). The acoustic reflex in eighth nerve disorders. <u>Arch</u>. <u>Otolaryngol.</u> 99:409-413.

Johansom, B., Kylin, B., and Langly, M. (1967). Acoustic reflex as a test of individual susceptibility to noise. Ac<u>ta Otolaryngol</u>. 64: 252-262.

Kaplan, H.J., Gilman, S., and Dirks D.D.,(1976)» Dynamic properties of acoustic ref1ex adaptation.

<u>TransanActaopthamolOtolaryngol</u>82:268-274.

Kapalan, H., Gilman, S., and Dirks, D.D., (1977). Propertics of acoustic reflex adaptation. Ann<u>. Otol.</u> Rhinol. Lar.86:348-356.

Liden, G., The stapadius muscle reflex used as an objective recruitment test; A clinical and experimental study In Wolstenholme and Knight, Ses<u>orineural Hearing Loss.</u> pp. 295-308 (Churchill London).

LorentodeNo', R. (1935). The function of the central acoustic nuclei examined by mean of the acoustic reflexes. <u>Laryngoscope.</u> 45: 573-595.

Mahon, A.E., and weiler, E.M., (1980). Farther test of a model for loudness coding after adaptation. Brit. J. Audiol. 14 (1): 7- 10

Margolis, R.H., and Popelka, G.n., (1975). Loudness and the acoustic reflex. J. Acoust. S.c Am. 58: 1330-1332.

Margolis, R.H., and Fox, C.M. (1977). A comparison of three methods for predicting haaring loss from acoustic reflex thresholds. J. speech and Hearing Res. 20: 241-255

Martin, F.N.and Brunette, G.W.(1980) Loudness in evaluating children and the aging for hearing aids. Proc. of Lexington Hearing Aid Conf.

McCandless, G.A. (1975). Special considerations in evaluating children and the aging for hearing aids. Proc. of Lexington Hearing Aid Conf.

McLeod, H.L., and Greenberg, H.J., (1977). Relationship between loudness and the acoustic reflex threshold for normal and sensorineural hearing impaired individuals. Nat. Conv. AM. Speech and Hearing Ass.

Matz, 0. (1952). Threshold of reflex contractions of muscles of middle ear and recruitment of loudness. Archs. Otolar. 55: 536-543.

Mirabells. A., Taub, H., and Teichner, W.H. (1967). Adaptation of lowdness to monawral at stimulation. J. Genar. Psychol. 76: 251-273.

Moore B.C.J.(1977). Loudness asaptation and fatigue Introduction to the Psycholo Hearing. p. 76. (The Macmillan Press Ltd. London).

Morgan, D.E.. and Dirka, D.D.(1973). Suprathrshold loudness adaptation. J. Acoust.Soc.Am.53: 1560-1564

Nellis, R.A., and Wiley, T.L. (1979). Recovery characteristics of the accustic reflex. J. Am. Aud. Soc. 4:184-189.

Olsen, W.d., Noffsinger,D., and Kurdziel, S. (1975). Acoustic reflex and reflex decay. Arch. Oto-Laryngol. 101:622-625.

Palva, T., (1955). Studies on perstimulatory adaptation in various groups of deafness. Larynogoascope, 65: 829-847.

Peterson, J., and Liden, G. (1972). some static charecteristic of the stapedial muscl reflex. Auditory 11: 97-114.

Petty, J.W ., Fraser, W.D., and Blliott, D.N.(1970). Adaptation and loudness decrement a reconsideration. J. Accust. Soc. Am. 47:1074

Popelka, G.R., (1978). !Detecting hearing loss from acoustic reflex thresholds, Natn. Conv. Am. Speech and Hearing Ass.

Rangasai, R. (1975). Verification of the hypothesis racruitment is an artifact—-Dissertation submitted to the University of Mysore, India, in partial fulfilment of the requirments for the degree of Msc., in Speech & Hearing.

Rapport, B, and Tait, C. (1976). Acoustic reflex threshold measurement in hearing aid selection Arcb.Otolaryngol. 102: 129-132.

Ross, S. (1968). On the relation between the acoustic reflex and loudness. J. Acoust. Soc. Am. 43: 766-779.

Siegel, S. (1956). Nonparametic ststistics for the Behavioural Sciences. (McCrawHill Kogakusha Ltd., Tokyo).

Sieminski, L.R., Durrant, J.D., Rosenberg, P.E., and Lovrinic, J.H.(1977). Stapedial reflex is normal Vs recruiting ears. J. Aud. Res. 17 (4): 251-261.

Sheehy, J.L. (1977). Impedance audiometry. In The Auditory Profile-Otorhinolaryngology.Audio-Digest.10.2.

Small, A.m., Brandt, J.F., and Cox, P.G. (1962). Loudness as a function of signal duration. J.Acoust. Soc. Am. 34: 513-514.

Small, A.M.(1963). Auditory adaptation. In Jerger, J. (ed.). Modern Developments in Audiology pp. 287-336. (Academic Fress, New York, London).

Snow, T. and MeCandless, G.A. (1976). The use of impedance measuras in hearing aid selection. Hearing Aid. J. 7:32-33.

Stelmachowicz P.G., and Lilly, D.J. (1979). An indirect estimate of auditory frequency selectivity from acoustic reflex measurments. J. Acoust.Soc.Am. 65: 1501-1508.

Stockinger, T.E., and Studebaker, G.A., (1968). Measurement of perstimulatory loudness adaptation. J. Acoust. Soc. Am. 44: 250-256.

Stokinger, T.E., Cooper, W.A., and Meissner, W.A. (1972). influence of binaural interaction on the measurement of perstimulatory loudness adaptation. J. Acoust. Soc. Am. 51: 602-607.

Stockinger, T.E., Cooper, W. A., Meissner, W.A., and Jones, K.O. (1972). intensity, frequency and duration effects in the measurement of monaural Perstimulatory loudness adaptation. J. acoust. Soc. Am. 51: 608-616.

Teas, D.C. (1970). Cochlear processes. In J.V. Tobias (ed.) Foundations of Modern Auditory Theory. (Vol.I). (Acadamic Press, New York).

Vyasamurthy, M.N. (1977). An objective verification of Small's model of loudness adaptation. Paper presented at the IX Annual Conference of Indian Speech and Hearing Association held at Bangalore.

Vyasamurthy, M.N., and satyan, H.S. (1977). Effect of masking and fatigue on acoustic reflex threshold, J.A.I.I.S.H

Ward, W.D. (1973). Adaptation and fatigue. In Jerger, J.(ed.) Modern Delvelpment in Auditory. Ch. 9. (Academic Press, New York).

Wersall. R. (1958). The tympanic muscles and their reflexes. Acta. Oto-laryngol. Suppl. 139: 1-112.

Wailer, B.M., Loeb,M., and Alluisi, E.A. (1972). Auditory adaptation and its relationship to a model for loudness J. Acoust. Soc. Am. 51: 638-643.

Weiler, E.M., and Gross, L.F. (1976). A positive measure of monaural heterophonic auditory adaptation. J. Aud. Res. 16: 20-23.

Weiler, E.M., and Hood, J.D., (1977). An improved model for loudness cod ing during auditory adaptation. 16: 409-506.

weiler, E.M., Linz, J., Mojdehi, and Glass, E.B. (1979). Investigation of the relationship between adaptation measured binaurally aad monaurally. Brit. J. Audiol. 13: 47-50.

Wilber, L.A. (1978). calibration Puretone Speech and Noise signals. In katz, J. (ed.) Heandbook of Clinical Audiology (2nd edn.) Ch.8 (The Williams and Wilking Co., Baltimore).

Wiley, T.L., and Karlovich, R.S. (1975). Acoustic-reflex response to sustained signals. J. Speech Hearing Res 18: 148-157

Wiley, T.L., Small, A.M., and Lilly, D.J. (1973). Monaural loudness adaptation. J. Acoust. Soc. Am. 53: 1051-1055.

Wilson, R.S., and Modride, L.M (1978). Threshold and growth of the acoustic reflex. J. Accoust. Soc. Am. 63: 147-154.

Wilson, R.H., Steckler, J.F., Jones, H.C., and Margolis, R.H. (1978). Adaptation of the acoustic reflex. J. Acoust. Soc. Am. 64: 782-791

Woodford, C.M., and Holmes, D.W (1977). Relationship between loudness discomfort level and acoustic reflex threshold in a clinical population. Audiol. Hear. Educ. J .3: 9-12.

APPENDIX-A

AN OBJECTIVE VERIFICARION OF SMALL'S MODEL OF LOUDNESS ADAPTATION*

Designation & Address

Lecturer in Audiology
All India Institute
of speech & Hearing
Manasaganfothri
Mysore - 570 006
INDIA

Jan,1977

*Paper presented at the IX Annual Conference of speech and Hearing Association held at Banglore, India, during Jan. 1977. (This paper got Dr. Desa's Best Paper Award).

APPENDIX - A

ABSTRACT

Small's model (1963) of loudness adaptation and the controversies prevailing with regard to the levelling off of simple adaptation above 60 dB have been objectively answered using Electroacoustic Impendance Bridge (Madsen 2072). The following conclusions are made:

1. Simple adaptation (Loudness adaptation measured at the intensity of the adapting stimulus) is linear with the intensity of the adapting stimulus beyond 60 dB level. The levelling off of simple adaptation above 60 dB as reported by other investigators (Palva, 1955; Jerger, 1957; Weiler, 1972) may be attributed to the adaptation of comparison ear owing to lateralization (cross over) of the adapting stimulus. In the present study, the influence of adaptation of non-test ear was completely ruled out as non-test ear was not made use of for measuring loudness adaptation unlike SDLB technique (non-test ear, in the present investigation, was used just for recording compliance changes). Further, the explanation of Palva and Karja (Weiler, 1972) that levelling off of simple adaptation may be due to spread of stimulation to internal hair cells, can no more be entertained in the light of the results of the present investigation.

2. Small's prediction that if adaptation is measured at an intensity less than that of the adapting stimulus, the amount of adaptation does mot depend on the intensity at which the ear is Adapted, but only upon the intensity at which adaptation is measued, is confirmed objectively by the present investigation.

3. Predictions inferred from Small's model of significantly lower adaptation when test tone intensity exceeds adapting tone intensity are objectively confirmed.

At present, studies are being carried out regarding asymptic state of adaptation and recovery of adaptation in the same lines of the present investigation.

INTRODUCTION

Ward (1973) distinguishes the phenomena commonly included under adaptation in two different ways whether they are observed during or after exposure to the acoustic stimulus (Concomitant or residual respectively) and whether they require one ear (Monaural) or two (Binaural) for their measurement.Examples for these four categories—concomitant monaural, concomitant binaural, residual monaural and residual binaural are: tone decay, parstimlatory adaptation, TTS and loudness reduction (measured by ABLB test) respectively.

In the present paper, loudness adaptation is measured after exposure to the acoustic stimulus and it is measured using one ear--the same adapted ear. The measurement at of adaptation is made objective using Electroacoustic Impedance Bridge (Madsen Z072). It is believed that elicitation of the acoustic reflex is directly related to the loudness experience of an acoustic stimulus (Metz 1952; Thomsen,1955: Evertsen et al, 1958; Terkildsen, 1960; Moller, 1961; Terkildsen, 1964; Lamb, Peterson and Hansen, 1968, Djupesiand, Plottorp and Winther, 1970; Jerger, 1970; Flottorp et al, 1971; Alberti and Kristensen, 1972; Petersem & Lidan, 1970; Fitzeland and Bartin 1974; Vyasamurthy, 1975; Rangsai, 1975), Based on this belief, difference in the magnitude of the reflex between pre-adapted test tone and post-adapted test tone at equal intensity levels is considered as a measure of loudness adaptation i.e. the amount of loudness adaptation in decibles is the difference between the intensity of the post adapted test tone and the intensity of the pre-adapted test tone which produces the same magnitude of reflex as that of the postadapted test tone. This way, loudness adaptation is measured in decibels objectively. Loudness adaptation measured in this manner may be termed objective residual monaural loudness adaptation (ORMLA).

Many techniques have been devised for measuring adaptation in its development, asymtotic stats and recovery. The simultaneous dichotic loudness balance (SDLB) technique is the one that has been most frequently used for measuring all of the aspects of adaptation. Studies relating to the amount of adaptation as a function of intensity, duration and frequency of the stimulus are in conflict. Hood (1950) found a roughly linear relation over the range of intensity values he investigated (40 dB SL to 80 dB SL). Jerger(1957) has demonstrated a linear relation from 10 dB to 60 dB SL, but above this level the function flattens out. Jerger(1957) Palva (1955) and Weiler (1972) have found no increase in adaptation as a function of adapting intensity above 60 dB. Elliott and Fraser (1970) summarize as follows:

> ...For the studies that have data points in common (Hood,1950; Palva, 1955; Jerger, 1957 and Wright, 1960) only Hood showed a substantial increase in the degree of observed adaptation beyond the 60 dB level. Two speculations as to why this levelling off of occurred present themselves. First, if crossover does operata so as to cause adaptation in the control ear and there is a linear relation between adaptation and intensity, then a levelling off of observed adaptation would occur at approximately the 70 dB point. This sort of spoculation is, of course restricted by the fact that two studies: Hood (1950) and Carterette (1956) did show linear relation continuing above 60 dB....The levelling off of adaptation at 60 dB, lies in the fact that the data are plotted in intensity units rather than in subjective loudness units. Carterette (1956) found a linear relation only when he made just such a transformation. Although a general statement might be that adaptation and the intensity of the adapting stimulus are linearly related, the upper limit of this function remains in doubt. More evidence is needed before such a statement can be made with confidence.

Further, Palva & Karja (as mentioned by Weiler, 1972) have suggested that the change in the function above 60 dB may be linked to a spread of stimulation to the internal haircells.

Small's model (1963) of loudness adaptation has been verified by some investigators (Egan. 1995; Hood, 1990; Weiler, 1972). It seems that objective verification of small's model of loudness adaptation in the lines of present investigation has not yet been attempted by any investigator. The present study is the first attempt ever made to verify Small's model of loudness Adaptation objectively. Also this study aims to throw light on the existing controversies with regard to the levelling off of loudness adaptation above 60 dB.

METHOD

Subjects

Four groups of normal hearing subjects in the age range of 18 - 22 years were tested, for four experiments: I, IIA, IIB and III. Subjects were selected on the criteria of:

1. Normal hearing in with ears ($\leq$ 20 dB HL ANSI, 1969) for frequencies from 250 Hz to 4 KHz
2. Normal tympanograms in both ears
3. Normal acoustic reflex thresholds in both ears
4. Increase in the magnitude of reflex with increase in the intensity of 1000 Hz tone i.e., subjects who showed visually noticeable changes in the deflection of Balance Meter (BM) needle for every 5 dB rise in intensity of 1000 Hz tone upon 105 dB SPL and visually noticeable changes for every

10 dB rise above 105 dB SPL were selected (at hidh intensity levels noticeable change in the deflection of BM needle occurred only for 10 dB steps).

Equipment

All data were obtained using an electroacoustic impedance bridge (Madsen Z072). Probe tone (220 Hz) of the bridge was calibrated for 89 dB SPL by using B & K Sound Level Meter (220)) with Octave Filter set (B & K 1613) attached to 2 cc coupler with 4144 (B & K) consenser microphone. Frequency of 220 Hz tone was checked by using 203 Timer/ Counter Eastern Electronics and Earphone output (Telex with MK-41/AR cushion) was calibrated using B & K SPL meter (2203) with Octave Filter Set (B & K 1613) attached to 6 cc coupler with 4144 (B & K) miorophone. Attenuator linearity was checked. Earphone output for 1000 Hz tons at different dial readings are given in Appendix 1.

Procedure

Four experiments were carried out using four groups of normal subjects: Group 1, Group 2, Group 3 and Group 4.

Experiment No.I. Experiment I was conducted to see whether simple adaptation (adaptation measured at the inten. sity of the adapting stimulus) remains constant above 60 dB. 10 selected subjects (6 F + 4 M) were tested (Group 1). The following procedure was followed fer each subject:

Step 1. Acoustic reflex threshold of Lt. ear was determined at 1 KHz. The procedure given in the Manual of Madsen

Z072 impedance bridge was followed. 1000 Hz tone was presented for 1.5 sec (there is a provision for presenting tones for 1.5 sec in the bridge). BM needle deflection positions and sensitivity knot position at different levels of 1000 Hz tone were noted. The different levels were: 80, 85, 90, 95, 100, 105, 115 and 125 dB SPL. At high inensity levels sensitivity knob of impedance bridge was set at '2' or '1'. Three reading were taken at each level for reliability. the readings were consistent. BM needls position and sensitivity knob position for different levels of 1000 Hz tone in a subject are given in Appendix 2.

Note: The above testing was done far all the subjects. prior to every adaptation test.

Step 2. 1000 Hz tone was presented continudusly to left ear of each subject for 7 min at 105, 115 and 125 dB ASL separately on differant days. At the end of 7-min adaptation, the tone was withdrawn and immediatly compliance control knob and sensitivity knob (probe tone was put off during adaptation) were adjusted until BM needls showed '0' (midline of the scale). Next, the same tone was presented again for 1.5 sec . BM needle deflection position was noted. adjustment of compliance control and airpump for middle ear pressure could be done within 5 sec. Thus there was 5 sec rest period before the ear was restimulated for the measurement of adaptation. BM needle position and sensitivity positon for post adapted 1000 Hz tone was compared with the same BM needle position and sensitivity position for preadapted 1000 Hz tone. For example -- If BM needle position and sensitivity position for preadapted 1000 Hz tone at 90 dB SPL is*4 (3) BM (S) and for post adapted 1000 Hz tone at 105 dB SPL is also 4 (3) BM (S). Then adaptation in dB measured at 105 dB SPL is equal to 15 dB ('.' 109 - 90), The rationale is that when 1000 Hz tone is presented at 105 dB SPL to the ear which is adapted for 7', the loudness of 1000 Hz tone will be decreased by an amount equal to the amount of adaptation. Consequently the magnitude of the reflex is also reduced. Reduction in the magnitude of the reflex is a measure of adaptation.

Experiment II 'A'. Expermrnt II 'A' and II 'B' were carried out to verify Small's prediction that when adaptation is measued below the intensity of the adapting stimulus the amount of adaptation does not depend upon the intensity at which the ear is adapted, but only upon the intensity at which adaptation is measured.

8 subjects (5F + 3 M) were tested for this experiment. Group 2, was used.

Procedure 1. Step 1 of experiment was carried out;

2. Amount of adaptation for 1000 Hz tone when presented continuously for 4 min at 125 dB SPL was measured at 115 and 105 dB SPL separataly on different days. The technique of measurement was same as the technique mentioned in step 2 of experiment I.

+4(3) means—-4 refers to Balance Meter reading, 3 refers to sensitivity knob position.

Experiment II 'B'. 7 subjects (4 F + 3 M) were tested for this study. Group 3, was used.

Procedure 1. Step 1 of experiment I was carried out.

2. Amount of adaptation for 1000 Hz tone when presented for 4- min continously at 125 dB SPL and 115 dB SPL was determined on different days using 1000 Hz test tone at 105 dB SPL. The technique of measurement was same as the technique mentioned in step 2 of experiment I.

Experiment III. This experiment was done to investigate whether lower adaptation results when adaptation is measued at an intensity higher than the intensity of the adapting stimulus.

Five subjects (3F+2M) were tested for this study. Group 4 was used.

Procedure 1. Step 1 of experiment was carried out.

2. Amount of adaptation was measured at 130 dB SPL and 120 dB SPL on different days after the ear was adapted to 1000 Hz tone at 120 dB SPL for 4 min. The technique of measurment was same as the technique mentioned in step 2 of experiment I.

Reliability. The subjects were retested for reliability on different days.

Experiment I. Table 1 reveals the amount of simple adaptation exhibited by normal hearing subjects when exposed to 1000 Hz tone continously for 7 min at 125, 115 and 105 dB SPL. Amout of adaptation was same during retest conditions for all the subjects at all the intensity levels tested. It is clear from the data that simple adaptation increases a function of intensity of 1000 Hz tone. This finding is in contrast to the observation of earlier investigators (Jerger 1997, Palva 1955 and Weiler, 1972) that simple adaptation remains fairly constant above 60 dB. The result of the present study proves beyond any deubt that simple adaptation is linear with the intensity of the adapting stimulus (1 KHz) even above 60 dB. Levelling off of adaptation above 60 dB as observed by other investigators may be attributed to the adaptation of comparison ear owing to lateralization of adapting stimulus. The amount of adaptation measured by using the present study is not at all affected by the adaptation of nontest ear as the nontest ear is not used for measuring loudness adaptation unlike SDLB technique (nontest ear, in the present study, is used just for recording compliance changes).

Farther. it is obvious from the results of the present study that the explanation of Palva and Karja (as mentioned by Weiler 1972) that the levelling off of simple adaptation

Table 1

Amount of simple adaptation for 10 subjects

No. of Subjects	Intensity 1 KHz tone in dB SPL					
	125 Amount of adaptaton in dB		115 Amount of adaptation in dB		105 amount of adaptation in dB	
	Test	Retest	Test	Retest	Test	Retest
1	20	20	10	10	5	5
2	20	20	10	10	5	5
3	10	10	5	5	5	5
4	10	10	5	5	0	0
5	20	20	10	10	5	5
6	30	30	15	15	5	5
7	20	-	10	-	5	5
8	10	10	5	5	5	5
9	20	20	10	10	5	5
10	30	-	15	-	5	-

- = Not test

Table 2

Amount of adaptation (in dB) to 1 KHz tone presented at 125 dB SPL for 4 continuously. Adaptation was measured at 115 dB SPL & 105 dB SPL

Sl. No. of subjects	4' 125	5" 1.5" 115	4'5" 125	1.5" 105
	Test	Retest	Test	Retest
1	10	10	5	5
2	15	15	10	10
3	20	20	15	15
4	25	25	15	15
5	10	10	5	5
6	20	20	10	10
7	15	15	10	10
8	20	20	15	15

above 60 dB may be due to apread of stimulation to internal hair cells caa no more be entertained.

Experiment II 'A'. Results of this experiment are given in table 2. Table 2 shows the amount of adaptation exhibited by 8 subjects to 1000 Hz tone when exposed continuously for 4 min at 125 dB SPL. Amount of adaptation was measured at 115 and 105 dB SBL seperately on different days after adaptation to 1000 Hz tone for 4 min at 125 dB SPL.

The results reveal that when adaptation is measured below the intensity of the adapting stimulus, the amount of adaptation does not depend upon the intensity at which the ear is adapted, but only upon the intensity at which adaptation is measured. The results confirm Small's prediction objectively.

Experiment II 'B'. Table 3 shows the amount of adaptation exhibited by 7 subjects to 1000 Hz tone when exposed continuously for 4 min at 125 dB SPL and 119 dB SPL on different days. Adaptation was measured at 105 dB SPL. Same amounts of adaptation were observed even when the ear was adapted to different intensity levels. Thus the results confirm Small's prediction objectively.

Table 3

Amount of adaptation (in dB) to 1 KHz tone
Presented at 125 dB SPL, 115 dB SPL for 4
was measured at 105 dB SPL

Sl. No. of subjects	4' 125 Test	5" 1.5" 105 Retest	4' 115 Test	5" 1.5" 105 Retest
1	15	15	15	15
2	10	10	10	10
3	20	10	20	20
4	15	15	15	15
5	25	25	25	25
6	20	20	20	20
7	20	20	20	20

Table 4

Amount of adaptation (in dB) to 1 KHz tone presented at 120 dB SPl for 4' continuously--adaptation was measured at 130 dB SPL and 125 dB SPL

Sl.No.of subjects	4' 120 Test	5" 120 Retest	4' 120 Test	5" 1.5" 130 Retest
1	15	15	10	10
2	20	20	10	10
3	10	10	0	0
4	10	10	0	0
5	10	10	0	0

Experiment III. Table 4 shows the amount of adaptation exhibited by 5 subjects when exposed to 1000 Hz tone at 120 dB SPL for 4 min continuouely. Amount of adaptation was measured at 120 and 130 dB SPL seperately on different days after the ear was adapted to 1000 Hz tone for 4 min at 120 dB SPL. This experiment shows that less adaptation results when adaptation is measured at an intensity higher than the intensity of adapting stimulus. Predictions, inferred from Small's model, of lower adaptation when test tone intensity exceeds adapting tone intensity were confirmed objectively.

In all the experiments retest values agreed with the test values indicating high reliability of the test procedure used (r=1.00).

Summary and Conclusion

Small's model (1963) of loudness adaptation and the controversies prevailing with regard to the levelling off of simple adaptation above 60 dB have been objectively answered using Electroacoustic Impedance Bridge (Madsen ZO 72). The following conclusions are made:

1. Simple adaptation (loudness adaptation measured at the intensity of the adapting stimulus) is linear with the intensity of tha adapting stimulus beyond 60 dB level. The levelling off of simple adaptation above 60 dB as reported

by other investigators (Palva, 1955; Jerger, 1957; Weiler, 1972) may be attributed to the adaptation of comparison ear owing to lateralization (Crossover) of the adapting stimulus. In the present study, the influence of adaptation of non-test ear was completely ruled out as non-test ear was not made use of for measuring loudness adaptation unlike SPLB technique (non-test ear, in the present investigation was uaed just for recording compliance changes). Further. the explanation of Palva and Karja (Weiler, 1972) that levelling off of simple adaptation may be due to spread of stimulation to internal hair cells, can no more be entertained in the light of the results of present investigation.

2. Small's prediction that if adaptation is measured an intensity less than that of the adapting stimmlus, the amount of adaptation does not depend on the intensity at which the ear is adapted, but only upon the intensity at which adaptation is measured, is confirmed objectively by tha pre-sent investigation.

3. Predictions, inferred from Small's model, of significantly lower adaptation when test tone intensity exceeds adaption tone intensity are objectively confirmed.

At present, studies are being carried out regarding adymptotic state of adaptation and recovery of adaptation in the same lines of the present investigation.

APPENDIX 'A'

REFERENCE

Albert: P.W.; and Kristensen, R (1972). Stapedial reflex reflex threshold decay - A normal study in clinical practice, Mayo Foundation . Impedance Symposium.

Djupealand, G.; and Flottorp, G (1970). Correlation between the Fowler Loudness balanca test, the Mitz recruitment test and Flottorp - Opheiums aural harmonics test in various types of hearing impairment. Journal of international Audiology 9: 156-175.

Kgan, J.P; (1955). Perstimulatory fatigue as measured by heterophonic loudness balance, J. Acoust. Soc. Am. 27: 111-120.

Elliott, D.N.; Fraser, W (1970). Fatigue and Adaptation. in Tobias, J.V (ed.). Foundations of Modern Auditory Thoery (Vol.1). (Academic Press, New York).

Ewertsen, H.W.; Filling, S.; Terkildsen, K., and Thomsen,K.A. (1958). Comparative recruitment testing. Acta. Oto-lar. Suppl 140: 116-122.

Filzeland, R.E.; and Barton, T.E.; (1974). The use of acoustic reflex and puretone thresholds for measuring loudness recruitment, paper presented at the Rational Convention of the American Speech and Hearing Associa--tion.

Flottorp, G.; Djupesland, G.; and Winther, F (1971). The acoustic reflex in relation to critical bandwidth. J. acoust. Soc. Am. 43-457

Hood. J.D.; (1950) Studies in Auditory Fatigue and adaptation. Acta. Oto. Laryng. Syppl. 92.

Jerger, J.F.; (1957). Auditory adaptation. J. Acoust. Soc. Am. 29: 357-363.

Jerger, J.;)1970). Clinical experience with impedance audiometry. Archieves of Otolaryngology 92: 311-324.

Kristensen, H., and Japsen,0.;(1952). Recruitment in Oteneurological diagnostics. Acta. Oto-Laryagologica, 42: 553-560.

Lamb,L.; Peterson, J.; and Harisen, S.;(1968). Application of the xetapedius muscle reflex measures in the diagnosis of auditory problems. International Audiology7:188-199.

Matz,0 (1952). Threshold of reflex contractions of muscles of middle ear and recruitment of loudness, Archieves of Otolaryngology 55: 536-543.

Moller, A.R.; (1961). Bilateral contraction of the tympamic muscle in man. Ann. Otol.Rhinol. Laryngol 70. 735.

Palva, T (1955). Studies on per-stimulatoyr adaptation in various groups of deafness. Larynogoscope 65: 829-847.

Peterson, J.; and Liden, G.;(1972). Some characteristics of the stapedial muscle reflex. Audiology 11: 97-114.

Rangasai, R (1975). Verification of the hypothesis—recruitment is an artifact - Dissertation submitted to the University of Mysore, India, in partial fulfillment of the requirements for the degree of MSc., in speech and Hearing.

Small, A.M.;(1963). Auditory adaptation. In Jerger.J (ed.). Modern Developments in Audiology. Ch.8 (Academic Press, New York).

Terkildsen, K.; (1960). An evaluation of perceptive hearing losses in childran based on recruitment determination. Acta. Oto-laryngologica 51: 476-484.

Terkildsen, K.;(1964). Clinical application of impedance measurement with a fixed frequency technique. Journal of International Audilogy 3: 147-155.

Thomaon, K.A.; (1955). The Metz Recruitment Test - Acta. Oto-laryngologica. 45: 544-552.

Vyasamurthy, M.n.;(1975). Effect of masking and fatigue on acoustic reflex thresholds. Paper presented at the conference of Indian Speech and Hearing Association held at Manipal in January.

Ward, W.D.;(1973). Adaptation and fatigue. In Jerger,J (ed.) Modern Developments in Audiology. 2nd edn. Ch.9 (Academic Press, New York).

Weiiler, E.M.;(1972). Auditory adaptation and its relationship to a model for loudness. J. Acoust.Soc.Am. 51: 638-643.

APPENDIX - 1

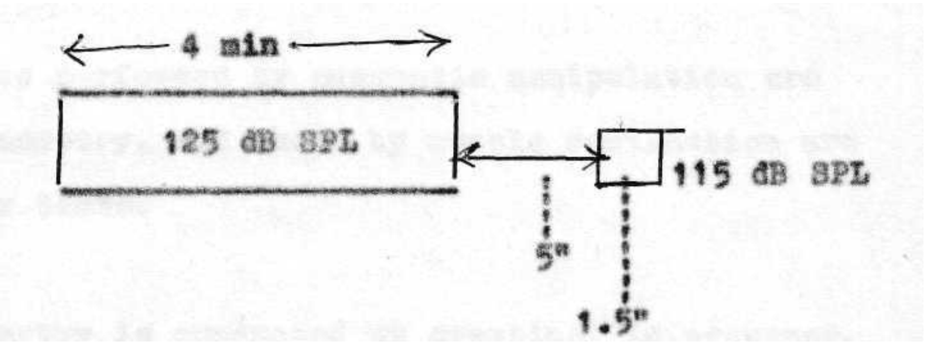
Dial Readings dB HL	Earphone output at 1 KHz in dB SPL
60	65
65	70
70	75
75	80
80	85
85	90
90	95
95	100
100	105
105	110
110	115
115	120
120	125
125	130

Note: Decimal points have been omitted.

Appendix - 2

Pressure in the ear canal (mm H_2O)	dB SPL of 1 KHz tone (pre-adaptation)	BM needle position	sensitivity Knob position
0	85	2	3
0	90	4	3
0	90	2	2
0	95	3	2
0	100	4	2
0	105	4.5	2
0	110	1	1
0	115	2	1
0	125	2.5	1

Example:



B.M. needle position and sensitivity knob position for the post-adapted test tone presented at 115 dB SPL is 3 (2)

BM S

The same magnitude of reflex is obtained for the pre-adapted i

test tone at 95 dB SPL (shown in boxes).

.'. Adaptation = 115 - 95 = 20 dB

APPENDIX - B

EXCERPTS FROM "SCHOOL FOR IMFEDANCE MEASUREMENTS

INTRODUCTION TO IMPEDANCE

Impedance is a technique for making measurements of the function and intensity of the middle ear system. Because the system is mechanical, the measurements can be mase objectively.

the technique is based upon measuring the changes in sound pressure level in the ear canal causad by manipulation of the tympanic membrane and the ossicular chain. The manipulation is accomplished either pneumatically or by middle ear muscle contraction.

The tests performed by pneumatic manipulation are called tympanometry, and those by muscle contraction are called reflex tests.

Tympanometry is conducted by creating, in sequence, positive and negative air pressures in a sealed ear canal and recording the changes in mobility of the tympanic membrance/ossicular chain system thus caused. Creating a positive air pressure of 200 mm (water gauge) in a sealed ear canal will stiffen the tympanic membrane and thus reduce its efficiency as a transmission link. In this state the T.M has roduced mobility and is said to have a low compliance, or in other words the passage of sound is recuced or impeded, and the T.M. is said to have a high impedance.

If a negative air pressure of 200 mm is applied, the T.M will again be stiffened, its compliance will be reduced and its impedance increased.

The point of maximum compliance (minimum impedance)will occur when there is no artificially induced stiffness i.e., when the air pressure in the external ear cannal equals the air pressure in the middle ear spaces. If the air pressure in the external canal is changed slowly from +200 to -200 mm the compliance, in a normal middle ear, wi11 change from low to high and bach to low.

In a normally functioning middle ear, contraction of either of the middle ear muscles will exert a pull on the transmission link (the link comprising tbe sympanic membrance and ossicular chain) and will thus increase the impedance of the system. If an audio stimulus at about 70 dB above threshold is presented to an ear, and the stapedial muscle contracts the impedance change can be observed. In the absence of stapedial muscle reflex, there is some abnormality of the middle ear.

The instrument used for measurement is referred to as an impedance bridge, the word bridge in this context implying an electrical circuit which compares two signals. When the two signals are equal, the bridge is said to be in balance. Any difference between the two signals will unbalance the bridge, and it is thus a simple matter to provide a meter whose deflection can be directly interpreted as a changes in one of the signals. If the other of the two signals is a standardized or reference signal, the result is an extremely sensitive and effective way of measuring small quantities.

The impedance bridge has two meters. The first is an electro - manometer, which is an accurate gauga for measuring the ear canal air pressure. The second is the balance meter which is operating as a sensitive sound level meter, for measuring the sound pressure level in the ear canal.

Reading of these meters are used to determine if the middle ear being investigated is normal or abnormal. In the presence of abnormality, the bridge offers further help in differentiating between the more common moddle ear pathilogies.

BASIC PRINCIPLE

The Modsen Z072 Impedance Bridge is one of a series of investments used to detect and measured middle ear functions. It can also detect and measure the action of middle ear muscles. The instruments advantage is that it is capable of making all measurements quickly and with no discomfort to the patient. The Z072 Impesance Bridge works on the principle that when a hard walled cavity has a calibrated audio tone applied to it, a sound presented levels (SPL) will be established. If the volume of such a cavity is large, the intensity of the tone must be relatively large to attain a given SPL within the cavity. conversely. If the cavity is small, the intensity of the tone necessary to attain the same SPL will be relatively smaller. When this sound pressure level is measured the volume of that cavity can be determined and any change in that cavity can also be dsitinguished.

TECHINICAL PREINCIPLES

Attached to the Z072 headband is a small metal case contsining a receiver and a microphone. The metal probe section contains three small pipes. soft eartips of different sizes enable the probe to make an airtight fit in the ear canal. A cavity is thus formed by the airtight closure of the ear canal terminated by the ear drum. A pure tone generator produces a fixed frequency of 220 Hz. termed the probe tone ,which is the basis for the acoustic impedance measurements. The probe tone is applied to the recolver, the sound output of which is coupled by a rubber tube to one of three pipes in the probe. The microphone, which is connected by a second rubber tube to another of the probe pipes, serves to monitor the SPL within the canal. The remaining pipe in the probe section is connected by flexible tubing to a pressure system consisting of a pump and electromanometer by mean of which specific positive or negative pressures can be applied to the ear canal.

The compliance control is a multi-turn potentiemeter acting as an attenuator to govern the probe tone intensity. When the Compliance Control is adjusted to give zero reading on the Balance Meter, the SPL in the ear canal is precisely 85 dB (55 dB above the threshold for normal hearing). This SPL is made to coincide with zero on the Balance Meter. The other side of the meter is connected to a very stable DC supply of 20 volts. When the microphone signal voltage equals 20 volts. The voltage at the Balance Meter terminal is zero, the polarity of the opposing voltages being much that cancellation occurs. When tbe SPL exceeds 85 dB the balance Meter reading is to tho right of centre zero and if below 85 dB,to the left of zero.

The main scale cursor for the Compliance Control traverses alternative scales, one for readings of Acoustic Impedance engraved in Acoustic Ohms and the other for Compliance reading engraved in Cubic Centimeters (cc). Acoustic impedance and Volume (cc) are in direct relationship for hard-walled cavities and it is on this basis that the Compliance control is calibrated. Thus, if the probe is fitted to a hand-walled cavity having a volume within the measuring range of the Z072, the volume, in cc, may be measured and read off the Compliance Scale.

When measurements are made on the ear, adjustment of the Z072 Compliance Control to a zero reading on tbe Balance Meter sets the SPL in the ear canal to 85 dB. For a given ear canal volume, the measured compliance will differ from that in a hard-walled cavity of similar volume due to absorption of acoustic energy at the eardrum and through the middle ear. As the absorption of energy increases, the compliance increases or, expressed another way, the acoustic impedance decreases.

The amount of absorption at the eardrum equals a certain incresse of the actual volume of the ear canal. It is determined, among others, by three separate factors, the eardrum itself, the ossicular chain, and the middle ear space.

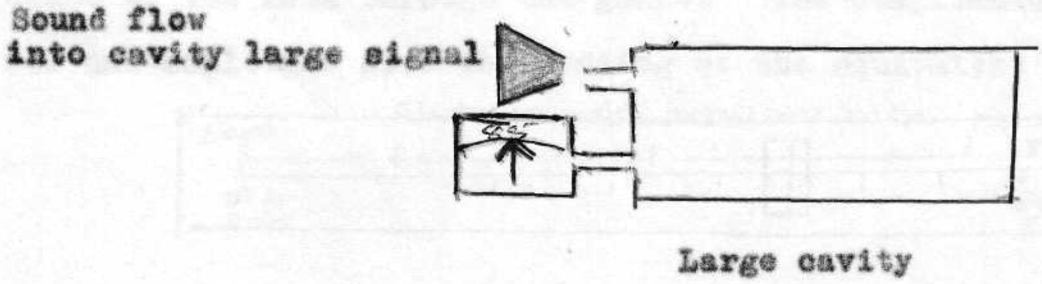
PRINCIPLES OF ACOUSTIC IMPEDANCE

Acoustic impedance is the resistance offered by an object to sound and it is maesurad in units termed acoustic ohms. The mobility of the object can also be measured and expresed as compliance. It has been customary to indicate the compliance is equivalent volume of air. Any stiffness can be expressed by such a specific volume.

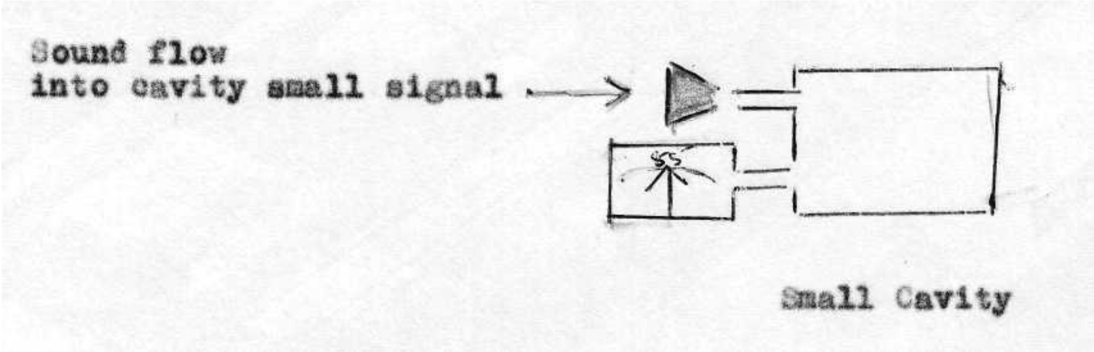
When sound strikes an object, some of the acoustic energy is reflected and some is absorbed, depending upon the nature of the material involved. Thus, when sound reaches the Tympanic Membrane (T.M), some of the acoustic energy is absorbed causing it to vibrate. The energy thus dissipated gives rise to the mechanical motion of the T.M. and the ossicular chain within the middle ear. Mechanically, the ear is a highly complicated and delicately poised structure. A normal T.M. and middle ear offer a relatively low acoustic impedance. implying that appreciable energy is absorbed and passed through the middle ear. If the eardrum is thickened or the middle ear contains fluid, the acoustic impedance will be increased which means that less energy will be absorbed and there will be a consequent loss of transmission. Likewise, if a negative pressure exits within the middle ear and the T.M. becomes stretched, the acoustic impedance will be incresed.

With the Model Z072, T.M. characteristics may be observed by the application of positive and negative pressures to the ear canal. The function of the intra-aural muscle reflexes may also be studied and the various observations are seen as changes in acoustic impedance. The correct clinical interpretation of the various measurements has to be considered and in order to make the best practical use of the model Z072 it is important to understand the principle involved.

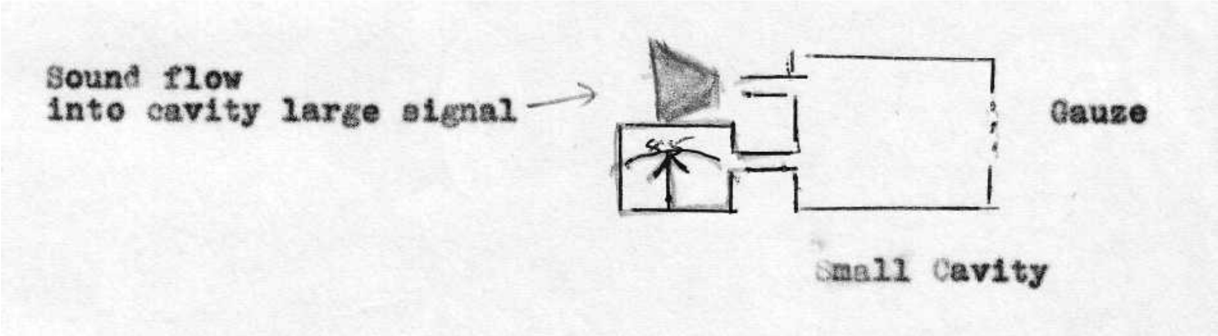
The volume of a hard-walled cavity may bed determined acoustically by the application of a pure tone of a fixed frequency and known energy, and measuring the Sound Level (SPL) within the cavity.



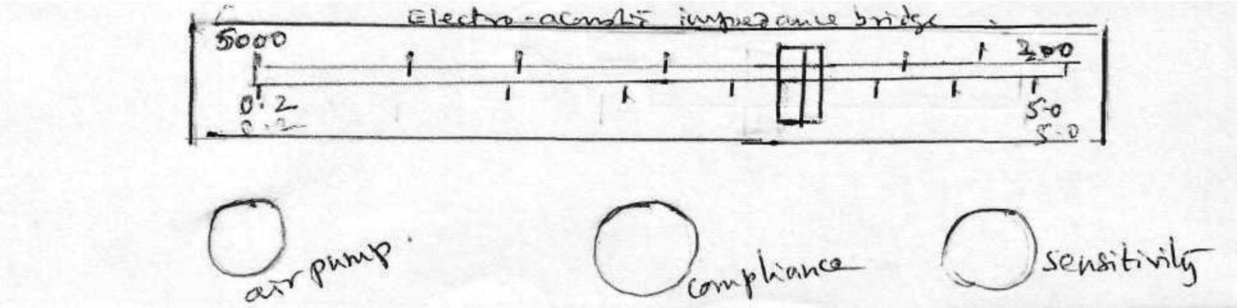
If the volume of such a cavity is large, the energy of the tone must be relatively large to attaind a given SPL within the cavity.

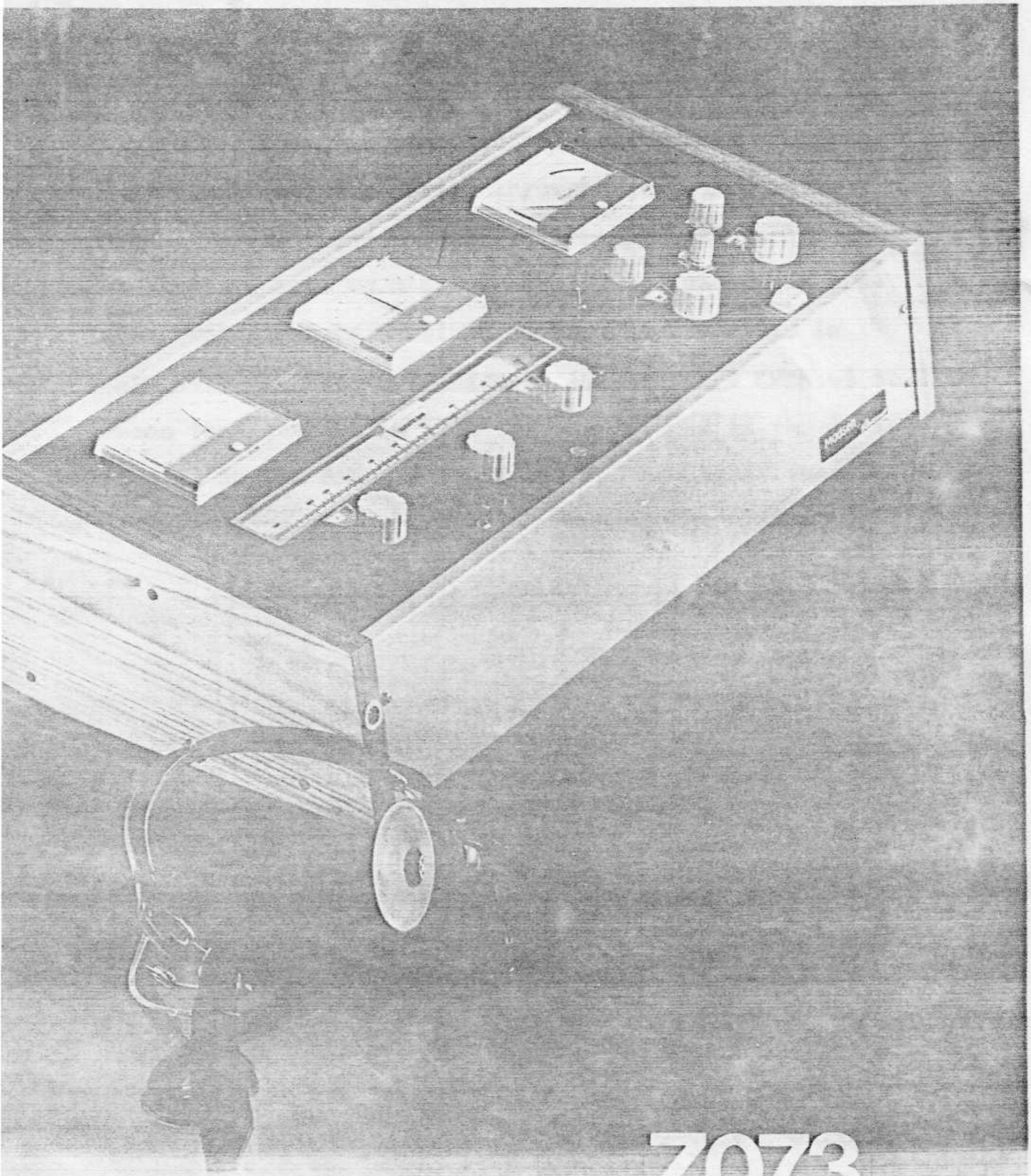


Conversely, if the cavity is small, the energy of the tone necessary to attain the same SPL will be relatively smaller.



If a gauze is inserted in one end of the small cavity more energy has to be applied to maintain the same SPL because of the leak through the gauze. The compiance control and scale now give the reading of the equivalent volume.

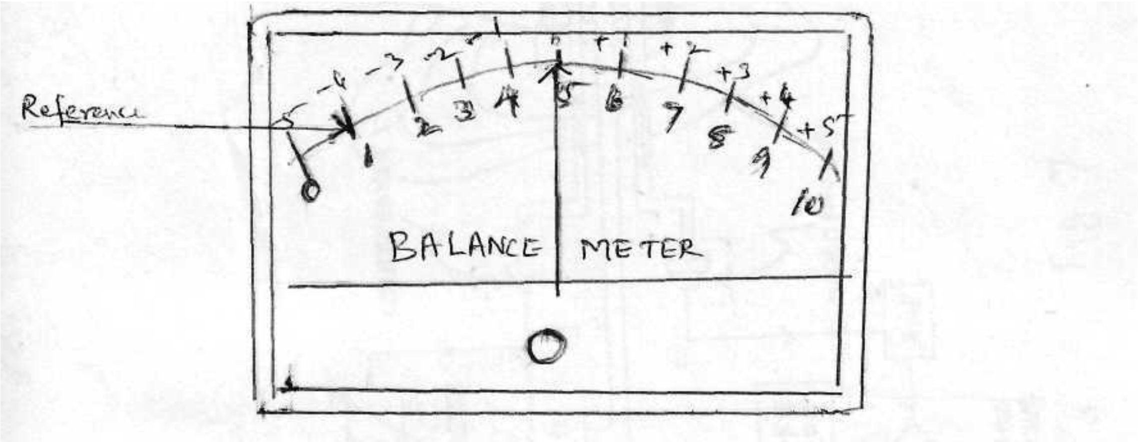




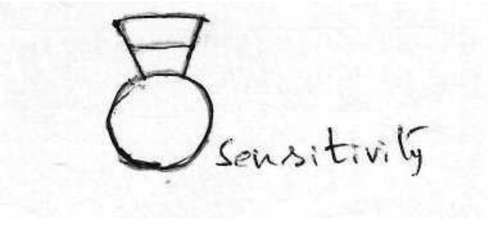
Z073

Madsen

The basic principle of the Model Z072 is that the compliance potentiometer controls the amount of energy that flows into the cavity through the probe, whilst the balance meter which (via the probe) is connected to the microphione, acts as a sound level meter showing a pre-set sound preasure level of 85 dB SPL when it is in balance. If the deflection is in the range from -5 to 0 it means that the SPL is less than 85 dB, and if the deflection is in the range 0 to +5 the SPL is higher then 85 dB.



The sensitivity switch can change the sensitivity of the balance meter in such a way that it will give full deflection for relatively large or small changes in SPL. In position 1 the sensitivity is such that it takes several dB changes is SPL to get full deflection on the meter (Tympanometry) whereas in sensitivlty 4 just a fraction of a dB change will cause full deflection (Reflex Text).



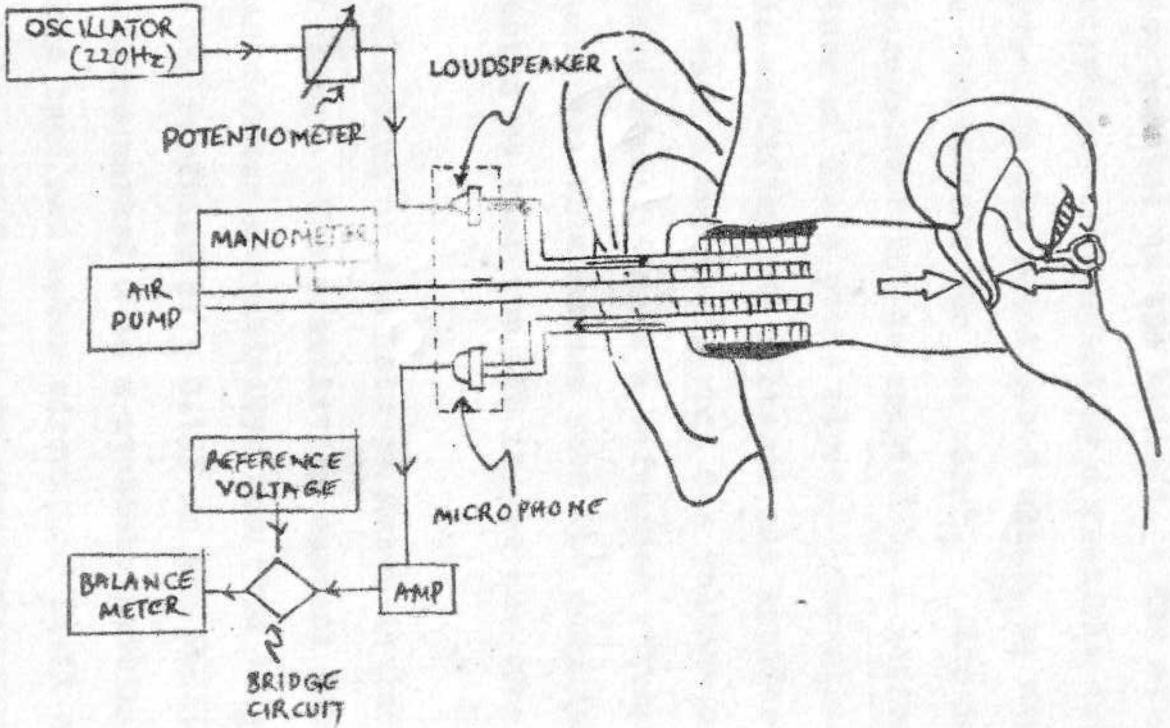

OSCILLATOR (220Hz)
POTENTIOMETER
LOUDSPEAKER
MANOMETER
AIR PUMP
MICROPHONE
REFERENCE VOLTAGE
BALANCE METER
AMP
BRIDGE CIRCUIT

Fig. 7

The impedance section of the Model Z072 consist of an oscillator producting a 220 Hz tone. This goes via the multiturn compliance potentiometer to a small loudspeaker in a case mounted on the headset. The sound output from the loudspeaker is coupled by a flexible tube to one of 3 small pipes in the metal probe which, by means of a plastic tip, is fitted into the ear canal. Also in the small case is a microphone which is coupled by a second flexible tube to another of the 3 probe pipes. the signal from the microphone is amplified aad filtered and applies to a bridge circuit in such a way that, whan the voltage of the amplified microphone signal equals a reference voltage, the meter will be in balance; this occurs when the compliance potentiometer is adjusted so that the SPL in the ear cannal is 85 dB.

Deflection of the Balance Water is indicative of compliance change. The sensitivity control provides four degrees of Balance Mater sensitivity: Position 1: ± 1 cc, Position 2: + 0.5 cc. Position 3: ± 0.125 cc and Position 4: ± 0.025 cc. The position marked 0 is a stand-by setting for switching off the probe tone and meter circuit. Small changes in compliance can be read from the Balance Meter scale which is engraved 5-0-5 and divided late units and half units. When it is desired to measure previsely small changes in compliance. reference should be made to the Conversion Charts which takes into account the setting of the Sensitivity control (Positions

1,2, 3 & 4) and the volume of the ear canal under investigation which must be measured.

The main scale associated with the Compliance control is calibrated in terms of Compliance (0.2 to 5.0 cc) and Accustic Impedancr (5000 to 200 acoustic ohms). When the wavelength of the probe tone is large in comparison with the volume, volume and acoustic impedance are in direct relation—ship for hard-walled cavities and it is on this basis that these scales are calibrated. Subject to due allowance being made for actual ear cavity size by reference to the Conversion Chartas the Balance Meter gives an accurate expanded interpretation of the main Compliance scale. By this means very small compliance changes can be measured. Note that clockwise rotation of the Compliance control gives Balance Meter deflection to the right and anti-clockwise rotation gives deflection to the left. Thus, for example, if the Balance Meter needle is reading full scale to the right, rotate the Compliance control to the left (anti-clockwise) to obtain a zero reading.

AIR PRESSURE SYSTEM

The third pipe in the metal probe section is connected by a flexible tube to the pressure outlet at the near of the instrument. The system comprises a multi—turn pump and electro-manometer scaled ± 400 mm (water gauge). The pump cantrol has a scale with a centre zero and extended lines on either side which become incressingly bolder towards the limits of pump-control rotation. The electro-manometer is based on a pressure transducer connected to both the ear canal and tha pressure system. Thus, the true pressure is displayed on the meter.

Pressures above or below atmospheric may be applied to the ear under investigation A pre-set control at the rear of the instruments marked zero Adj (39) is providid. For zero adjustment of manometer (1) leave the probe open whilst adjusting. The zero setting of the manometer (1) is indepeadent of atmospheric barometric changes.

FITTING THE HEADSET

The headset is fitted with a single audiometric earphone by means of which the stimulus for the muscle reflex tests is applied by the audiometer section. Before carrying out may tests it is important to remove any wax from the patient's ears which may block the three small apertures in the probe and rener the instrument unserviceable.

The relative positions of the probe and audiometer earphone will depend upon the particular tests to be carried out, For general tympanometry including middle ear pressure, cavity volume and eardrum impedance measurements, the probe is placed in the ear under investigation, and the audiometer earphone on the contralateral ear. For muscle reflex measurments, the audiometer earphone is placed on the ear under investigation, and tha probe is placed in the oppsosite ear. In facial nerve examinations, the probe is placed in the ear under investigation and the opposits ear is stimulated by the audiometer to setermine whether the intraaural muscle reflex action is present.

Always set the pump control to zero before inserting the probe to ensure that the full pump range is available. Adjust the audiometer earphone so that the cushion aperture is directly facing the ear canal. Select a suitable mushroom shaped plastic or cellular nylon foam eartip for the probe - push the eartips on to the probe to make a flush fit. Insret the probe into the external meatus making sure that the probe apertures do act come into contact with the ear canal. When inserting the probe, pull the pinna upwards and backwards to straighten the ear canal and make insertion easier Also, ask the patient to open his jaw whilst inserting, as this widens the ear canal. In cases where it is difficult to get a seal, apply a little vaseline to the tip; this will make it easier to slide it in and at the

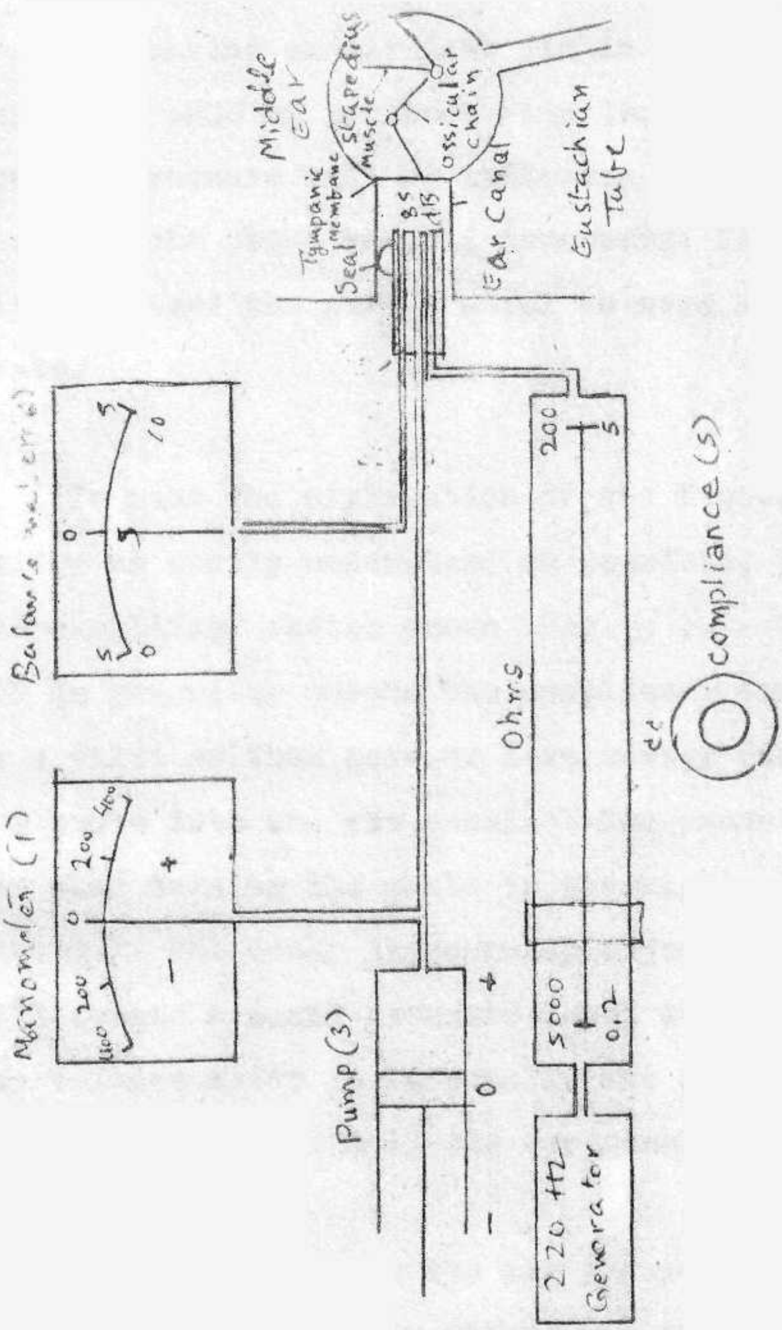

Manometer (1)
400
200
0
200
400
+
−
Balance meter(6)
5
0
0
5
10
Pump (3)
+
0
−
220 Hz Generator
5000
0.2
Ohms
200
5
cc
compliance (5)
Seal
Tympanic membrane
85 dB
Ear Canal
Middle Ear
stapedius muscle
ossicular chain
Eustachian Tube

Fig. 8.

same time if forms a better seal. Too much vaseline may obstruct the three small pipes. Always check that the probe is making an airtight fit in the ear canal by applying about +200 mm pressure with the pump control. Any loss of preassure will be indicated by the manometer. Reposition the probe and, if necessary, fit a different eartip. Re-set the pump control to zero before commencing tests.

To make the explanation of the function of the Madsen Bridge as easily understood as possible, please refer to the simplified sketch shown (Fig. 8). The tone from the 220 Hz generator passes the compliance coatrol which acts as a valve so that more or less energy (tone) earn be fed via the probe into the ear canal. The amount of energy increases when turning the scals to the right, towards a larger cavity. The scale is normally adjusted to that the energy will create a sound pressure level in the ear canal of 85 dB. The balance meter is internally set so that it will show a balance when the SPL in the ear canal is 85 dB.

The pump controls the air pressure in the ear canal and the manometer shows the actual pressure. when the piston in the pump is moved to the right (toward +) a positive pressure is, via the probe, created in the ear canal and when the piston is moved to the left a negative pressure is reached The manometer will at all times show the actual pressure.

Tympanometer

Tympanometer is used to test mechanical condition of the middle ear. The test includes checking of the mobility of the tympanic membrane and associated ossicles, fluid and air pressure in the middle ear as well as eustachian tube function.

The tympametry test using the impedance mater can be explained in the following simplified way. Under normal conditions the air pressure in the middle ear equal the pressure in the ear cannal, because the ear canal as well as the middle ear, via the eustachian tube, has normal atmospheric pressure. The tympanic mambrane will therefore normally be in its neutral relaxed position free to move, and show a normal compliance. If, in a normal ear, a pressure of +220 is applied to the ear cannal, the tympanic membrane will be moved inwards and clamped. It will have less mobility and be less compliant and the balance meter will give a difletion to the right. When the pressure in the ear cannal is reduced, the tympanic members will move back towards its relaxed position, it will become more compliant and therefore the balance meter will move to the left. When the pressure in the ear canal equals the pressure in the middle ear, the tympanic membrance will be in its most compliant position and the balance meter will indicate that by giving a minimum reading on the red scale.

If a negative pressure is applied to the ear canal in a normal ear, the tympanic membrane will be moved outwards and clamped. It will have less mobility and be less compliant and the Balance Meter will show a low compliance by deflacting to a higher number on the red scale. This will be more or less the same situation as when the positive preasure was applied. When the negative pressure is reduced the tympanic membrane will move towards the relaxed position, it will again become more compliant, and therefore the needly on tbe balance meter will move to the left. When the pressure in the ear canal equals the pressure in the middle ear, the tympanic membrane will be in Its most compliant position and the balance metter will indicate that by giving a minimum reading on the red scale.

To find the actual pressure in a middle ear, the pressure sis therefore changed from +200 mm towards a negative pressure. The Balance Meter is watched and the air pressure that creates the lowest reading on the red scale (highest compliance) equals the pressure in the middle ear.

Acoustic Reflex Test

When a sound of a relatively high intensity (70 - 90 dB above threshold) is applied to an ear. the stapedius muscle in both ears will contrast. When the muscle contracts it will make a slight pull on the ossicles, which will be transmitted to the tympanic membrance and result in a small change of compliance. Because the compliance change is very small, it is important that the pressure in the external canal exactly equals the middle ear pressure, whether it is 0, -20, -40 etc, in order to ensure that the tympanic membrane in its moast compliant position.

When the stimulus is presented to one ear, the acoustic signal goes via the middle ear, cochlear and the nerve system to the brain. If the loudness sensation is enough, the brain will, through the 7th nerve, cause the stapedius muscles in both ears to contract.

When the stapedius muscle contracts it makes the system less compliant, therefore the balace meter will give a deflection to the right as long as the stimulus is on. In normal hearing a stimulus intensity of 70 - 90 dB HTL will cause a stapedius muscle contraction. Normally the contraction will be clearly seen on the balance meter whan sensitivity switch is set at 3. If the defltection is very small the sensitivlty can be incressed 5 times by setting sensitivity switch in position 4. If white noise is used the required intensity for eliciting the stapedius reflex is less than for pure tones. Here it should be emphasized that the W.N. is calibrated in S.P.L.

APPENDIX - C

Earphone (Telen - 1460 with Mz - 41/AR cushion) outputs at different frequencies and at different intensity dial readings.

Dial Readings in dB HL.	Output in dB SPL		
	500Hz	1000 Hz	2000 Hz
70	86.0	79.0	75.0
75	90.5	84.0	79.5
80	95.0	89.0	85.0
85	100.0	94.0	89.5
90	105.5	99.0	94.5
95	110.0	104.5	99.5
100	114.5	109.0	104.0
105	119.0	114.5	109.5
110	124.0	119.5	113.5
115	129.0	124.5	116.5
120	133.5	130.0	123.5
125	138.0	134.5	129.5

NOTE : 1. Decimal points were not consideree while reporting the results.
NOTE : 2. Madsen Z073 has a prevision for a verrnier cenlo.
NOTE : 3. In the present study all the intsnsity levels are empressed as multipies of 5, for convenience.