THE OBJECTIVE ESTIMATION OF LOUDMESS DISCOMFORT LEVEL THROUGH AUDITORY BRAINSTEM RESPONSE

SAVITHA kAMATH
Reg. NO.M9821

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कायेन वाचा मनसेन्द्रियैर्वा
बुध्यात्मनावा प्रकृतेः स्वभावात् ।
करोमि यद्यत् सकलं परस्मै
नारायणायेति समर्पयामि ।।

I am humbly dedicating this
"YAJNA" - THE WORK,
being the result of my efforts by concentrating my body,
speech, behaviour, sensitivity, energy, mind and thought
To, THE LORD
possessor of all wealth and protector of universe.

and

"Vanaja ma' m"
This piece of my work,
which is created due to
her great ability to lead and
illuminate my thoughts, is dedicated to her

CERTIFICATE

This is to certify that this Dissertation entitled : ***THE OBJECTIVE ESTIMATION OF LOUDNESS DISCOMFORT LEVEL THROUGH AUDITORY BRAINSTEM RESPONSE*** is the bonafide work in part fulfilment for the degree of Master of Science (Speech and Hearing) of the student with Register No.**M9821**

Mysore
May, 2000

Director
All India Institute of
Speech and Hearing
Mysore 570 006.

CERTIFICATE

This is to certify that this Dissertation entitled : ***THE OBJECTIVE ESTIMATION OF LOUDNESS DISCOMFORT LEVEL THROUGH AUDITORY BRAINSTEM RESPONSE*** has been prepared under my supervision and guidance.

Mysore
May, 2000

Vanaja C.S
Lecturer in Audiology
Department of Audiology
All India Institute of
Speech and Hearing
Mysore 570 006.

DECLARATION

This Dissertation entitled: ***THE OBJECTIVE ESTIMATION OF LOUDNESS DISCOMFORT LEVEL THROUGH AUDITORY BRAINSTEM RESPONSE*** is the result of my own study under the guidance of Mrs. Vanaja,C.S., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other diploma or degree.

Mysore
May, 2000 **Reg. No.M9821**

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INTRODUCTION

Hearing is one of the most important senses for communication. From birth onwards, important links with the environment are forged and maintained through the sense of hearing. We rely on our hearing to alert ourselves as well as to bring to us the pleasures of sound both natural and man-made. Our hearing also performs a reassuring function which is continuously transmitting information about the environment. This hearing to sounds also become intolerant sometimes and cause discomfort to the individuals due to its excessive loudness. The loudness discomfort which depicts the loudness growth in an individual is one of the important parameters that is of concern clinically.

The loudness discomfort level (LDL) defines the upper limit of the individual's usable hearing. The loudness discomfort level has been measured by clinicians for the following purposes:

- To determine the presence of recruitment/cochlear pathology (Dix, 1968; Davis, 1960; Hood and Poole, 1966a).

- To select an appropriate hearing aid saturation sound pressure level (McCandless and Miller, 1972a; Shapiro, 1975, 1976; Cox, 1981).

Loudness discomfort level can be measured through both subjective and objective methods.

Subjective method : The measurement of LDL clinically was first done by Hood and Poole (1966a). Since then a number of investigators have studied LDL in patients with hearing loss using a variety of stimulus (Hood and Poole, 1966b; Woodford and Holmes, 1976; McCandless, 1976). Generally while estimating LDL the patient is instructed to signal either verbally or by whatever method is decided on, when the stimulus given is uncomfortably loud. They are reminded to signal only when the level would be intolerable.

Measuring LDL through these subjective methods may not be possible in difficult-to-test population, young children and individuals with unreliable/inconsistent responses. Hence several objective methods have been proposed to obtain LDL in patients who cannot respond for subjective LDL. This includes measurement of acoustic reflex threshold (ART) and auditory brainstem response (ABR). There have been equivocal results regarding the usage of ART for the estimation of LDL (McCandless and Miller, 1972b; Morgan et al. 1979).

The latency-intensity function (L-I function) of ABR has been used to study the loudness growth. The slope of the ABR wave V L-I function has been the parameter most frequently used to study the loudness growth as it is robust and stable morphological feature of ABR. As L-I function reflects the effect of different types of hearing loss on, loudness growth, several authors have tried to correlate the loudness growth to L-I function (Serpanos, et al. 1997; Smyth, et al. 1991), giving their own correlation factor and regression equation to determine the loudness perception.

Thornton, et al. (1987) tried to predict the value of LDL through the slope of L-I function using the regression analysis and gave an equation relating subjective LDL for clicks and the slope of L-I function. They reported that equation is applicable for different configuration of hearing loss. But effect of type of hearing loss was not assessed.

Need for the study

In earlier studies relating the slope and LDL (Thornton, et al. 1987), general relation was depicted in the form of an equation which is common for all types of hearing loss. In the literature it is reported that the slope of L-I function is affected by type of hearing loss (Fowler and Durrant, 1994; Fria, 1980) and configuration of hearing loss (Gorga, et al. 1985; Fowler and Durrant, 1994; Borg, 1981; Coats and Martin, 1977; Galambos an Hecox, 1977). This in turn may affect the LDL predicted for clicks through L-I function. Therefore, a single equation may not suit for different types of hearing loss. Clinically LDL for clicks is not used much either for setting maximum SSPL for hearing aid or for administering any suprathreshold tests. Hence there is a need for the study to arrive at an equation for predicting LDL for speech and/ or puretones/NBN, through L-I function.

Aim of the study

The present study was designed to

1) find out whether there is a relation, between the subjective LDL obtained for puretones of 2KHz, 4KHz, speech stimuli and L-I function of wave V in subjects with sensori-neural hearing loss.

2) If yes, is it possible to predict subjective LDL based on L-I function of wave V.

REVIEW OF LITERATURE

The sense of hearing can be explained with various descriptions such as hearing threshold, discrimination threshold, threshold of discomfort, adaptation threshold etc. The threshold of discomfort defines the upper limit of individual's usable hearing. Various terms as loudness discomfort level (LDL), uncomfortable loudness level (UCL), maximum threshold of pressure (MTP), discomfort level or tolerance level are used synonymously. LDL, UCL and TD being the most common.

Although all these terms have the same connotation, the procedures advocated and the values obtained by the investigators of the phenomenon differs widely. As a result, one should not consider these terms as representing equivalent auditory sensations without examining the instruction and procedures that were employed. The choice of LDL is the preferring terminology (Hawkins, 1980).

The physiological correlate of discomfort of the loudness sensation is not accurately known. Neimeyer (1971) quotes "threshold of discomfort, indicates that overload of the sensory cells is commencing, and thus does not exert a protective function, but at least indicates the need to protect the peripheral receptor". Lerche and Schulze (1958) also reported that the human ear's threshold of discomfort and beginning damage risk for continuous noise is at an appropriately equal sound level. In relation to this, Neimeyer (1961) demonstrated that discomfort of loudness sensation is not dependent on the centrally added total loudness of sound but on the elementary loudness integrated peripherally.

LDL can be measured in hearing level (HL), sensation level (SL) or sound pressure level (SPL). Hood and Poole (1966a) advocated the expression of LDL in terms of SPL rather than sensation level as SPL was a more consistent measure. This is borne out of the studies where they found the inter ear correlation consistently higher for LDL measured in SPL than in terms of SL (Stephens and Anderson, 1971).

Applications of Loudness Discomfort Levels

Watson (1944) was the first to introduce the concept of LDL as a clinical measure. But it was not used as a clinical measure until it was properly quantified and validated by Hood and Poole (1966a) (Priede and Coles, 1971). Since then LDL has received increasing usage in clinical audiological practice especially in cases with bilateral sensorineural hearing loss. The applications of LDL test are as follows:

(1) To determine the presence of recruitment.
(2) To establish the maximum presentation level for suprathreshold test.
(3) As a guide for setting the maximum output from an amplifying system.

(1) **To determine** the **recruitment**

Recruitment is the abnormally rapid growth of loudness with increasing stimulus levels (Hallpike and Hood, 1960), seen in individuals with cochlear pathology. Hood and Poole (1966a) advocated the use of LDL for determining recruitment where reduced LDL determined the presence of recruitment. Dix (1968) said LDL test is of particular relevance since it constitutes a very simple method of assessing the presence of loudness recruitment in cases of bilateral hearing loss. Dix (1968) report that in the case of neural hearing loss the LDL's are generally higher than the conductive group. This was based on their previous experience of loudness balance tests in these two respective groups. In subjects with unilateral conductive hearing loss, the loudness balance curve remained parallel to the normal, but displaced from it by the amount of hearing loss, while in unilateral sensorineural hearing loss the phenomenon of recruitment reversal was seen. Davis (1960) reported recruitment in sensorineural hearing loss individuals. Those with sensorineural losses are not protected from the annoyance of loud speech and noise as are those with conductive hearing losses. For these individuals the transition from hearing little or nothing to hearing sounds very loud is abnormally abrupt. Hence with sensorineural hearing loss the range of comfortable hearing between the inaudible and the top level is greatly narrowed because of loudness recruitment. This is one of the most common symptoms associated with sensorineural hearing loss together with other symptoms such as tinnitus, poor speech discrimination, breakdown in temporal integration. Hence in such cases the loudness discomfort level would be reduced leading to reduced dynamic range. Some patients find a given level of speech uncomfortable, because of its discomfort produced by the physical pressure of the sound. Woodford and Holmes (1976) obtained LDL for sensorineural hearing loss individuals at equal or lower SPL's than for normal listeners. Shapiro (1976) reported that mean LDLs for puretones in group of sensorineural individuals with an average hearing loss of approximately 60 dB SPL ranged from 112 to 118 dB SPL, in the speech frequency range.

Hood and Poole (1966b) also investigated LDL as a function of hearing loss. They measured LDL for puretones for 100 patients with Meniere's disease and 100 subjects with unilateral cochlear hearing loss due to other etiologies. Hearing loss for both group of subjects ranged from 0 to 80 dB HL. He concluded that there was no discernible upward trend of the LDLs with increasing hearing loss. When median LDLs were computed, the results suggested a non-linear relationship between LDL and hearing loss. Median LDLs increased as hearing loss was above 50 dB HL. However, McCandless (1976) presented contradicting results that there was no average increase of 20 dB HL in LDL for a speech stimulus as hearing loss increased from 10 to 80 dB HL. This suggested that mean LDL estimates for sensorineural hearing loss individuals may be dependent on the magnitude of hearing loss. This controversy might be due to the presence of different etiology causing cochlear pathology in sensorineural hearing loss individuals.

No equipment other than a standard audiometer is required for the LDL tests. The test is thus available to any practicing audiologist and can be carried out in routine practice when testing for a subject's threshold of hearing as well as while differentially diagnosing the auditory disorders (Hood and Poole, 1966a,* Dix, 1968).

(2) **To establish the maximum presentation level for suprathreshold test.**

As the LDL is the index to determine the tolerance of an individual, one should establish the LDL before administering any suprathreshold test so as not to discomfort the individual. Before speech identification tests, tone decay test, suprathreshold adaptation test <STAT), masking etc. the LDL should be established. It has also been reported that there is deterioration of performance on speech identification tests at LDL. Dirks et al. (1981) conducted a study to determine whether speech recognition improves at signal levels at or above the LDL for a group of listeners with sensorineural hearing loss. The results indicated that for most listeners with mild to moderate sensorineural hearing loss, maximum speech recognition performance could be achieved using presentation levels at or below the individual's LDL.

(3) **To establish the maximum saturation sound pressure level from the amplifying system.**

During hearing aid evaluation procedures, the LDL has been considered as an estimate of the optimal saturation sound pressure level for amplification by defining an upper limit beyond which amplified sounds becomes uncomfortable for a listener (McCandless and Miller, 1972a; Shapiro, 1975, 1976). It is generally agreed that the maximum output from a hearing aid should not exceed the subject's LDL. LDL lower than saturation sound pressure level (SSPL) 90 might lead to the dissatisfaction with hearing aid. The subject may use the hearing aid at less than optimum gain settings to prevent loudness discomfort or may ultimately reject the hearing aid (Munro, et al. 1996). However, this relationship is not easily defined as electroacoustic data are usually measured in a 2cc coupler and auditory measurements are usually obtained from supraaural transducers calibrated in a 6cc coupler. Cox

(1981) aimed at investigating this relationship. The results revealed that real ear saturation pressure was 115-120 dB SPL and LDL values were around 110 dB SPL when probe tube microphone system was used to measure the SPL of both variables. Therefore a rule was given to choose an appropriate hearing aid where SSPL 90 data are consulted and matched to the individuals LDL at different frequencies

$$\text{SSPL90} = (\text{LDL} + 3 + \text{receiver correction})\ \text{dB SPL}.$$

Three decibels were added to the measured LDL to estimate the stable level. It was further recommended that if a perfect match is not available at a particular frequency, the SSPL 90 at that frequency may be less than what the above rule specifies, but not greater. Thus, measurement of LDL play an important role in hearing aid evaluation in terms of setting SSPL.

Estimation of LDL

LDL can be measured through various methods. There are various subjective as well as objective procedures for determining in the LDL and the loudness growth.

Subjective procedures

Subjective procedures involve the active participation of the subject where he has to indicate when the signal is uncomfortably loud. The obtained LDL vary depending on the several factors. Some of factors that affect LDL are discussed here.

1) **Test stimuli**

Different types of stimuli have been used to obtain LDL. The most common stimuli being cold running speech (Carhart, 1946; Silverman, 1947; Schmitz, 1969; Zink and Alpiner, 1968; Hodgson, 1977) and general conversation (Briskey, 1980; Carhart, 1946; Davis etal. 1946; Dirks and Morgan, 1983; Foumeir, 1968; Morgan, Dirks, Bower and Kamm, 1979; Staab, 1975). Advocates of these stimuli report that speech is more realistic than puretones, which rarely occur in everyday listening and usually are not meaningful. Moreover LDL for speech can be obtained within less time than required to measure LDLs at several puretone frequencies. Puretones have also been used in some of the studies (Watson, 1944; Silverman, 1947; Zink and Alpinen 1968; Hood and Poole, 1966b; Priede and Coles, 1971; McCandless and Miller, 1972a; Morgan and Dirks, 1974; Woodford and Holmes, 1976; Berger, 1976: Dirks and Kamm, 1976). Narrow bands of noise is another stimuli that has been used to measure LDL. Investigators argue that puretones and narrow bands of noise are frequency specific, and thus enable greater precision than speech in limiting SSPL during hearing aid selection (Walleniills, 1967; Morgan etal. 1974; Shapiro, 1975).

Silverman (1947) compared LDLs for various stimuli and reported that LDL for speech was approximately equal to 10 dB higher than for puretones (average of 8 frequencies) for normal hearing persons, but this difference was not observed for hearing impaired individuals. Similarly Davis et al. (1946) and Dudich et al. (1975a) found speech LDLs were about 7 dB higher than puretones in sensorineural hearing loss individuals. Beattie and Boyd (1986) reported that LDL for puretones were not accurate predictors of the LDL for speech in mild to moderate sensorineural hearing loss individuals. Type of puretone stimuli used can also affect the measured LDL. Stephens (1970) observed higher LDL values with pulsed Bekesy than with continuous Bekesy stimuli.

On the other hand, a few studies have reported no significant differences between LDLs depending on the stimuli used. Dirks and Kamm (1976) found no significant difference between LDL for puretones at 500 and 2000 Hz and spondiac words in normal hearing individuals. Due to flattening of equal loudness contours at higher intensities (Fletcher and Munson, 1937) and the diminished effect of stimulus band width on loudness summation at higher intensities (Zwicker, et al. 1957), small differences between various stimuli may reasonably be observed, (Dirks and Kamm, 1976). Similarly Edgerton et al. (1980) reported little or no differences among LDLs obtained using 5 commercially available speech materials in individuals with mild to moderate sensorineural hearing loss.

2) **Rise time**

The temporal characteristics of the signal also influence the LDL. Much longer rise time for a given hearing level setting might be expected to be unpleasant and thereby giving rise to higher LDL values (Priede and Coles, 1971). Vigran, et al. (1964) showed that with 0.6 to 2.4 secs bursts of broad band noises at 70 and 100 dB SPL shortening the rise time from 1 sec down to 25 msecs caused a change in sensation of loudness equivalent to 2 and 4 dB increase in sound pressure level

(SPL). Priede and Coles (1971) gave the upper limit of 25 msecs and lower limit of 15 msecs to be appropriate rise time for measurement of LDL.

3) **Psychophysical methods**

Various psychophysical methods which are used clinically to establish LDL act as a source of variability. Very few studies have reported the effect of methods as such on the LDL. Stephens (1970) and Priede and Coles (1971) found that the tracking method gave about 10 dB higher LDLs than the method of limits. But Morgan et al. (1974) report equal LDL values for a 1 kHz tone using these two methods. Beattie and Sheffler (1985) compared LDL obtained through the method of limits and method of adjustment. It was observed that order of methods used affected the LDL but not the actual method. Other psychophysical methods proposed for clinical determination of LDL are an ascending method of limits with three crossings (Stephens and Anderson, 1971; Shapiro, 1975; Denenberg and Altschuler, 1976), and a simple ascending approach with no specific definition or criterion for level determination (Schmitz, 1969; Hood and Poole, 1966a; Silverman, 1947; Berger, 1976). Morgan, et al. (1974) suggested that the method of constant stimuli was best for research purposes.

5) **Instructions**

Instructions given to the individual about LDL affect its measurement. As the physiological mechanism which underlie the various instructional sets vary, phraseology should be selected carefully (Beattie et al. 1980). It is generally agreed that the discomfort is typically due to a true loudness sensation resulting from cochlear stimulation, whereas dizziness occurs from vestibular stimulation. Tickle and pain sensation are tactile in nature and arise from stimulation of nerve endings in the pinna, external auditory meatus, tympanic membrane and/or middle ear structures (Beattie, et al. 1980).

The importance of instructions in measurement of LDL was shown by Silverman (1947) who developed three instructional sets labelled "discomfort", "tickle" and "pain". He found that 15 normal hearing individuals had discomfort at 117 dB SPL, tickle at 129 dB SPL and pain for 138 dB SPL for speech stimulus. Similar findings were also observed with hearing loss individuals.

Beattie, et al. (1980) compared the LDLs for speech obtained through McCandless and Bergers instructions so as to select saturation sound pressure level for hearing aids. The difference in LDLs was found to be significant The hearing-impaired individuals showed significantly higher LDLs with Berger's instructions when compared to other (See Appendix for instructions). Hence different instructions lead to different SSPL's.

Hawkins (1980) asked the clients to indicate "initial discomfort", "definite discomfort" and "extreme discomfort". Different LDLs were obtained for 3 types of criteria Bomstein and Musiek (1993) also reported the differences in terms of LDL obtained for two different instructions. Therefore the choice of instructions as well as phraseology becomes an important consideration in measuring LDL.

5) **Listener's Experience**

Silverman (1947) reported that speech discomfort level varied depending on the listener's experience. LDL was about 10 dB higher for the final session than for the initial session in subjects with normal hearing, but this was not observed in sensorineural hearing loss individuals when Schmitz (1969) obtained speech LDLs for 3 measurements over a 2 week period. Priede and Coles (1971) reported that LDL values vary depending upon the previous occupational or other exposure to intense noise. LDL values were 3-7 dB lower for individuals who were exposed to noise than for the people who were not exposed to noise.

6) **Transducer type**

The type of transducer is another variable which is to be considered while measuring LDL. Stephens and Anderson (1971) reported no differences in LDL when determined under headphones and free field situation. Earlier Stephens (1970) had also reported similar results. However, Priede and Coles (1971) compared the LDLs for stimuli presented through telephonic TDH-39 ear phones and insert earphones and reported a difference of 6.7 dB. They explained this on the basis of non-linearity of acoustic output of the particular insert receiver supplied, for the audiometer, slightly greater harmonic distortion and greater intersubject variability in placement of receiver which might lead to larger standard deviation in case of inserts.

Berger (1976) recommended that LDLs should be determined with puretones under earphone to determine the acceptable SSPL of the hearing aid Alpiner (1975) recommended that it should be measured using speech under earphones and sound field.

7) **Monoaural vs. binaural determination**

LDL varies depending upon whether it is obtained for monoaural or binaural stimuli. Stephens and Anderson (1971) reported a difference of 3 dB between monoaural and binaural determination of LDL with LDL for monoaural being greater.

8) **Personality**

As LDL is a subjective measure it may vary with the personality of the individual also. Stephens and Anderson (1971) measured LDL and correlated with their various personality measures. There was **a** consistent negative correlation between LDLs and the measures of anxiety. However none of the correlations with personality measures attained levels of significance.

9) **Hearing Sensitivity/Type**

Investigation of LDL among patients with hearing loss was considered as an initial step in the development of procedures for defining optimal characteristics for amplification. The normal ear should be able to tolerate speech at hearing levels of 90-100 dB HL without experiencing discomfort (Martin, 1975; Newby, 1972). It is expected that a hearing-impaired person can tolerate speech at similar or higher hearing levels. Silverman (1947) and Davis et al. (1946) were among the earliest researchers to compare LDLs in normal and hearing-impaired listeners. LDLs were obtained for several stimuli at 110-120 dB SPL for normal listeners and at intensities greater than 120 dB SPL for hearing-impaired subjects. The hearing-impaired patients included both conductive and sensorineural sites of lesion. Hood and Poole (1966a) noted that subjects with conductive or 8th nerve lesions generally demonstrated LDLs at higher intensities than normal listeners. For sensorineural hearing loss individuals, the LDL is greatly reduced and has equal or lower levels of LDL than normals (Woodford and Holmes ,1976). Thus the LDL values vary with type of hearing sensitivity.

Test-Retest Reliability of LDL

Few studies have examined the reliability of LDL in sensorineural hearing loss subjects, Berger, et al. (1982) presumpted that the test retest reliability of LDL will be better with sensorineural loss individuals because of their reduced dynamic range. They examined the test retest reliability of acoustic reflex threshold(ART), LDL and most comfortable loudness level (MCL). The results showed that ART had the best test retest reliability, LDL had the good test-retest reliability and MCL showed the poorest test retest reliability. They further concluded that a single LDL measurement has only fair reliability, LDLs and MCLs obtained by averaging a number of points on a Bekesy tracing, and MCLs obtained with descending approach have good reliability. On the contrary, Beattie, et al. (1980) suggested that a good estimate of the intra-session LDL can be obtained using only one or two trials.

It has been reported that instruction used has an effect on the reliability changes. Borstein and Musiek (1993) used two instructions to obtain LDLs (i) the listeners were to indicate when they "would choose not to listen for any period of time" (ii) The listeners were to indicate when they "would choose not to listen for 15 minutes or longer". The reliability was high for the first criteria.

Thus, a review of literature indicates that a number of factors, need to be considered while estimating LDL . Even when all these variables are controlled, success of obtaining a valid measure of LDL is limited by an individual's ability to make reliable loudness judgements. Some individuals for eg. infants, mentally retarded, difficult-to-test population often cannot make such judgements. To overcome the effects of these and to obtain reliable LDL, various objective methods have to be sought.

Objective Procedures

Objective procedures do not require any voluntary response from the individual and hence the source of variability is lesser than that for subjective procedure.

1) **Prediction of LDL through acoustic reflexes**

The relationship between LDL and acoustic reflexes and hence prediction of LDL through acoustic reflexes has been controversial and inconclusive in literature. McCandless and Miller (1972b) found that ART for speech occurred at about 6 dB below LDL for speech. They stated that the appearance of the acoustic reflex at the same levels as does discomfort strongly suggests physiological significance to discomfort. They suggested a formula ART + constant (6 dB) could serve as an estimate of the LDL and could be used to limit or set the maximum power output of hearing aids. However, the constant recommended by various investigators has varied from as low as 6 dB (McCandless and Miller, 1972b) to as high as 35 dB (Niemeyer, 1971). On the other hand, the finding of LDL lower than ART has also been reported (Dudich, et al. 1975b).

Olson and Hipskind (1973) reported that differences were negligible between levels for maximum acoustic reflex and LDL for puretones. For speech the ART was 18.5 dB below LDL. McLeod and Greenberg (1979) used a well defined method of constant stimuli presentation using simple instructions to compare LDL and ART for speech and puretone stimuli for normal and sensorineural hearing-impaired subjects. Both LDL and ART were found to be significantly higher for the hearing-impaired group. For the puretone stimuli, LDL for the hearing-impaired group was at or below the ART. A multiple regression analysis indicated a significant correlation between LDL and ART. Both puretone and speech ART successfully predicted LDL within

+/- 10 dB for a high percentage of subjects. Contrary to this, various other investigators (Margolis and Popelka, 1975; Woodford and Holmes, 1976) have reported little or no relationship between loudness measures and ART. Ritter et al. (1979) demonstrated that ART correlates too poorly with the LDL measurements to permit an accurate prediction of loudness discomfort level. They contribute this variations to instructions used, type of test stimulus, hearing sensitivity of the subjects (normal hearing or sensorineural hearing loss) and transducer used for stimulus presentation. Morgan, et al. (1979) measured LDL and ART for subjects with normal hearing using several speech stimuli as well as broad band and speech spectrum noise. The purpose of the investigation was to determine the LDL for a variety of representative speech samples and to determine the relationship between the LDL and ART for selected speech and noise stimuli. Results indicated that for all stimuli, LDL measurements were relatively constant, but ART measurements decreased significantly for wideband noise stimuli as compared with the speech stimuli. As individual data were characterised by wide variability, prediction of LDL from ART was unwarranted. Greenfield, Wiley and Block (1985) also reject the use of the acoustic reflex measures in the estimation of an individual's LDL.

These equivocal results warrant the need for more investigation regarding the relation between LDL and ART. One of the limitations of using ART for the prediction of LDL is its absence in subject with middle ear pathologies as well as those with severe hearing loss.

2) Auditory Brains tern Response

Objective methods for estimating the loudness growth have been proposed using electrophysiological measures also. Thus far, however, investigations have not firmly established a direct link between electrophysiological tests and loudness growth. The auditory brainstem response remains one of the most useful clinical procedures for the objective estimation of auditory sensitivity and for the examination of auditory system integrity to the level of Brainstem (Jacobson, 1994). Several investigators have asserted that loudness growth could be estimated using click evoked ABR recordings (Galambos and Hecox, 1977, 1978; Gibson and Ruben, 1978; Picton et al. 1977; Yamada, et al. 1979). Various parameters of the ABR have been suggested as indicators of loudness. These include the wave V absolute latency (Rosenhammer et al, 1981a), slope of the L-I function (Galambos and Hecox, 1977, 1978; Gibson and Ruben, 1978; Picton et al. 1977; Yamada, et al. 1979), interaural latency differences (Rosenhammer et al. 1981b) and threshold (Conijin, et al. 1990).

The slope of the ABR wave V L-I function has been the parameter most frequently used in attempts to study loudness growth as wave V latency is the robust and stable morphological feature of the ABR. Some investigators have attempted to relate loudness growth to more general aspects of wave V L-I function, such as the overall slope values (Bauer, et al. 1975; Darling and Price, 1990; Howe and Decker, 1984).

Research in psychophysical area suggest that the overall slope value may not accurately characterise the entire loudness growth function (Hellman and Miselman, 1990; Knight and Margolis, 1984). Studies that failed to find a relationship between loudness growth and the ABR suggest that slope of the wave V L-I function may not be related as much to the perceptual phenomenon of loudness as to the configuration (Gorga, et al. 1985) and or degree (Smyth et al. 1991) of the hearing loss. Various factors affect this latency intensity function.

(1) Type of pathology/hearing loss

Conductive Pathology - A conductive pathology primarily attenuates the sound reaching the cochlea, producing significant latency shifts and waveform changes in the ABR (Fowler and Durrant, 1994). The L-I function represents the progressive parallel latency shift of the normal function that occurs as the degree of the conductive hearing loss increases (Fowler and Durrant, 1994). The amount of shift is related to the degree of hearing loss (Fria, 1980). For relatively large losses, the L-I function has the illusion of becoming steeper and converging toward the normal L-I function (Fowler and Durrant, 1994).

Cochlear Pathology - There is a steep rise in loudness growth function at high intensity level and loudness function is similar to normals despite the presence of hearing loss (Hall, 1991). Wave V latency decreases as a function of the degree of loss and at higher intensity levels slope becomes steeper and reaches the normal value (Hall, 1991).

(2) Configuration of Hearing Loss

Conductive Pathology **-** Though there is a shift in L-I function corresponding to the amount of air-bone gap, configuration of hearing loss also affects the L-I function. Gorga, et al. (1985) reported that L-I function was steeply sloping in a case of high frequency sloping conductive hearing loss, much as in the case of a sensorineural hearing loss. These results reflect the differing contribution of apical vs. basalward regions of the organ of corti according to the sensitivity of low and high frequency hearing respectively (Fowler and Durrant, 1994). According the Fowler and Durrant (1994), in flat conductive losses the L-I function shifts parallely-depending on the degrees of loss significant changes in the waveform beyond level dependent effects are not expected, i.e. to say at threshold levels of 35 dB or less conductive vs. cochlear groups are difficult to distinguish.

Cochlear pathology **-** Two mechanisms (auditory recruitment and cochlear travel time) are proposed by various investigators to account for the latency-intensity function in normals and sensory loss (cochlear pathology) (Coats and Martin, 1977; Galambos and Hecox, 1977; Gorga, et al. 1985;Yamada,et al. 1979). Fowler and Durrant (1994) hypothesize that high frequency hearing impairment alters the normal cochlear generator sites for ABR wave I, but not the basilar membrane sites for ABR wave V. With high intensity stimulation, which exceeds the degree of hearing loss, wave V continuous to be generated in part by basal cochlear activity as well as more apical activity and latency is reasonably normal. At lower intensities wave I disappears and wave V latency increases markedly because only more apical regions of the cochlea are activated. The L-I function hence shifts to the right, as a result and prolonged latencies are simply transmitted up the brainstem pathways, reflected as a delay in the latency of wave V (Hall, 1991). Hearing losses confined to the low frequencies have no appreciable effect on click evoked ABR latencies. Then the cochlear region that can respond is altered by the configuration of the hearing loss in an intensity dependent way. The net result would be normal wave V latencies at high intensities and prolonged responses at lower intensities with concomitantly steeply sloping L-I function (Gorga, et al. 1985).

Thus it has been reported in literature that abnormal growth of loudness, seen in some cases of cochlear hearing loss, may be suggested through steeply sloping wave V L-I function (Galambos and Hecox, 1977, 1978). This conclusion is based upon correlations between abnormal growth of loudness and steeply sloping L-I function. Gorga et al. (1985) criticised this, as it is based on limited number of studies. Findings from previous studies that attempted to establish a relationship between the loudness growth and the ABR have been equivocal. In fact Pratt and Sohmer (1977) and Wilson and Stelmack (1987) concluded that neural activities recorded at the brainstem level do not give rise to subjective loudness estimates. This conclusion was based on findings that electrophysiologic responses show little variability across subjects and recordings while loudness magnitude estimations show appreciable intersubject and intersession variability. Therefore ABR components were believed to represent neural codes rather than signs of actual auditory experience. Serpanos, et al. (1997) report that there are only few empirical studies that have supported a relationship between loudness growth and wave V L-I function. This might be due to (1) the lack of physiological basis, as to how latency and loudness might be related as well as relation of ABR to those complex internal processes which lead to auditory perception (2) methodological factors such as measurement of loudness growth itself(Gorga et al. 1985).

Various studies that have been conducted to investigate loudness growth and electrophysiological techniques are discussed here.

Smyth, et al. (1991) tried to investigate the relationship between the audiogram slope and the wave V L-I function slope with respect to recruitment. The results of the study indicated no significant relationship between audiogram variables as slope, degree of hearing loss and the slope of wave V L-I function. The results suggested that neither loudness recruitment nor audiometric configuration influenced the slope of the L-I function. Serpanos, et al. (1997) studied the relationship of loudness growth and the L-I function of wave V of click evoked ABR in listeners with normal hearing and cochlear hearing loss. They analysed the slope for the behavioral and electrophysiological intensity functions. The loudness growth functions for the groups with cochlear hearing loss approximated the normal formation at high intensities. The ABR wave V L-I function for the group with a flat configuration of cochlear hearing loss approximated the normal function at high intensities and had the slope of 0.8/10dB. The group with sloping configuration had a slope of 0.55/10DB. Significant relationship was obtained between loudness and the ABR wave V L-I function for the groups with normal hearing and flat configuration of cochlear hearing loss. They suggested that ABR can be used to estimate the loudness growth at least for individuals with normal hearing and those with cochlear haring loss of flat configuration. Predictive equations given to predict loudness in dB nHL for clicks presented at a 61.4/sec, repetition rate for an individual listener were as follows:

For subjects with normal hearing

Perceived loudness (dB nHL) = 202.87 - (19.87 X ABR wave V latency)
+/- 9.84 (SE,dB nHL)

For subjects with cochlear hearing loss

Perceived loudness (dB nHL) = 140.03 - (9.61 x ABR Wave V latency)
+/- 10.18 (SE/B nHL)
SE = standard error of estimate

They concluded that this electrophysiologic procedure may be an useful index for the estimation of the psychologic perception of loudness.

Similarly, Thornton, et al. (1987) also had tried to correlate the subjective loudness discomfort level and loudness growth measured through ABR wave V L-I function in both normal hearing and hearing loss groups. The equation to predict subjective LDL for clicks in both groups was as follows:

Subjective LDL =I+15 dB

Where I is the intensity at which the wave V L-I function slope becomes less than 0.1 msec/10 dB. This equation estimated the LDL values for each of the normal subjects to within 5 dB. They reported that this preliminary study was to investigate the feasibility of using ABR to estimate LDL. Though the subjective estimates of LDL are to be preferred because they involve more of the auditory system than the ABR or ART estimates, for patients who cannot give subjective responses an objective measure is required.

Thus a review of literature indicates that there have been equivocal results regarding the loudness growth and L-I function. Hence this present study was taken up to investigate the relationship between the loudness perception where the psychophysical aspect of loudness discomfort level was tried to correlate with L-I function of wave V of ABR, and obtaining the LDL measure through L-I function of wave V.

METHODOLOGY

The aim of the study was to obtain an objective estimation of loudness discomfort level using auditory brainstem evoked response.

I SUBJECTS

Twenty two ears of 18 subjects with age ranging from 15 years to 80 years (mean age : 56 years) were taken up. Among them, females were 4 in number and males were 14 in number.

Subjects who met the following criteria were included for the study :

(1) **Hearing Status** : Sensorineural hearing loss with puretone average between 26 dB HL and 70 dB HL in the test ear. The difference between these thresholds at different octaves was within or equal to 20 dB.

(2) **Loudness Discomfort Level**: (1) loudness discomfort level equal to or less than 110 dB HL for puretones of 2 kHz, 4 kHz and for speech (2) Loudness discomfort level equal to or lesser than 90 dB nHL for clicks.

(3) **No history/indication** of **neurological problems.**

II INSTRUMENTATION

A. Audiometer: A calibrated double channelled diagnostic audiometer was used to obtain air conduction, bone conduction thresholds, loudness discomfort level of puretones and speech.

B. Immittance meter : A calibrated middle ear analyser was used to carry out tympanometry and reflexometry.

C. **ABR recording instrument**: Biologic evoked potential (Navigator) system with EP 317 software was used to record ABR.

III TEST ENVIRONMENT

The test was carried out in a quiet room with adequate lighting and comfortable temperature.

IV TEST PROCEDURE

The following tests were carried out on all the subjects.

Puretone audiometry : Puretone thresholds were established using modified Hughson and Westlake Procedure (Carhart and Jerger, 1959). Loudness discomfort level for puretones of 2 kHz, 4 kHz and speech was measured. The subject was instructed to mention the loudest intensity level that he/she would be able to tolerate for 2 minutes (Minimum time required for ABR recording).

Immittance evaluation: Tympanometry and reflexometry was done to rule out the middle ear pathology.

Whenever indicated, **special tests** were carried out to rule out retrocochlear pathology

ABR recording

(i) *Patient set-up*

The patients were seated in a comfortable position to ensure a relaxed posture and minimum rejection rate.

(ii) *Electrode placement*

Silver chloride electrodes were fixed after a thorough skin surface cleaning with skin preparing paste and then fixed with standard EEG paste at their respective sites. Cz - Al - A2 placement was used. The electrodes were suitably secured in place with surgical tape.

(iii) *Measuring impedance*

Impedance with reference to the common electrode was measured for the given channel. It was ensured that the impedance was less than 5000 ohms and the inter-electrode impedance was less than 2000 ohms.

ABR was then recorded using the following test protocol.

Test protocol

(i) *Stimulus parameters*

Transducer - Headphones (TDH-39) with MXH-41/AR cushions.
Type of stimulus - Clicks
Number of stimuli - 2000
Rate-30.1/sec
Polarity - Rarefaction

(ii) ***Recording parameters***

Gain - 50,000
Filter setting - 100 Hz to 3000 Hz
Notch filter - out
No.of channels - one

Initial recording was carried out at loudness discomfort level for clicks. Then the intensity was reduced in 10 dB nHL steps so as to record ABR at LDL, LDL-10, LDL-20 and LDL-30 dB nHL (0 dB nHL = 35 dB SPL).

Wave V L-I function was recorded for the above levels and slope was calculated. (The time at which the wave V starts falling was taken as the latency).

RESULTS AND DISCUSSION

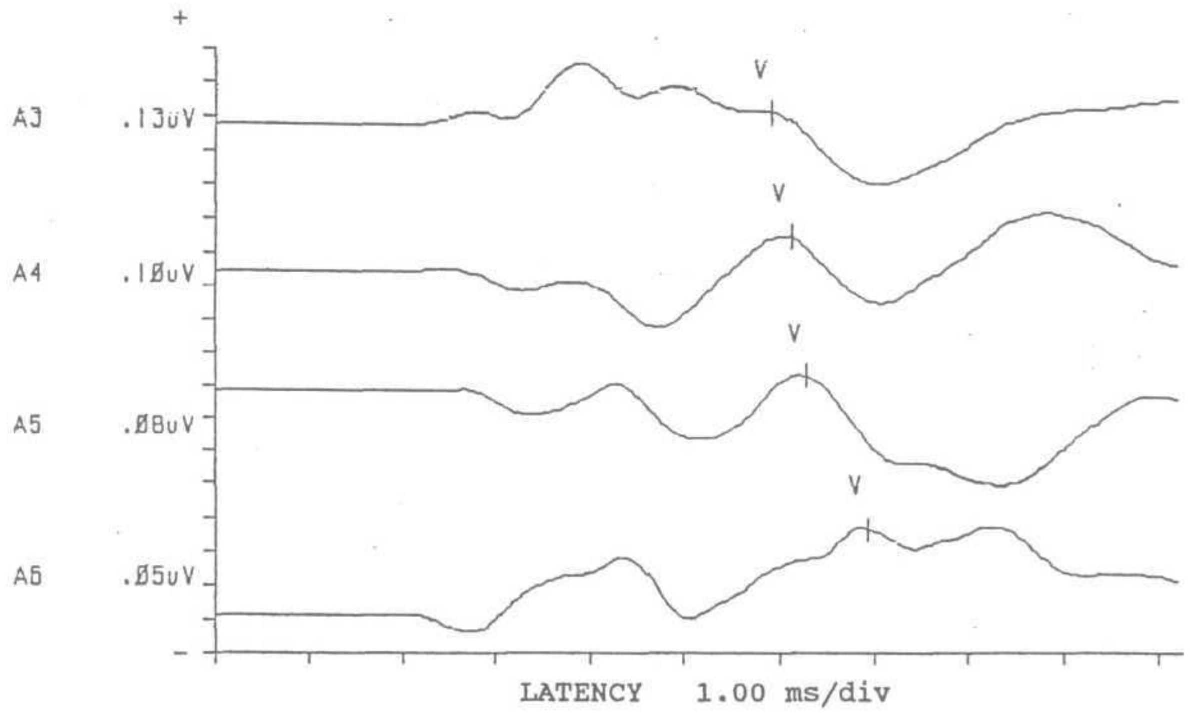
The objective of the study was to estimate subjective LDL through the L-I functions of the wave V of ABR. For twenty-two ears with LDL less than or equal to 90 dB nHL, the L-I function was carried out and the slope was measured.

1. L-I Function of wave V

Table-1: Mean latency of wave V and standard deviation at different intensity levels.

Stimulus level	Mean latency of Wave V in (msec)	Standard deviation
LDL	5.42	0.46
LDL-10	5.82	0.45
LDL-20	6.11	0.53
LDL-30	6.28	0.37

Table-1 shows that the mean latency of wave V reduced from 6.28 msecs to 5.42 msecs as the intensity was varied from LDL-30 dB nHL to LDL. The latency of the wave V was delayed at LDL-30 dB nHL level but reached near normal values at LDL i.e. 5.42 msecs as in fig.l. This normal wave V latency at LDL, in spite of the presence of the average hearing loss of 47.5 dB HL indicated the presence of recruitment. This supports the findings of Hall (1991), who reported that there was a steep rise in loudness growth functions at high intensity



LATENCIES (ms)

	Intensity level [dB nHL]	I	II	III	IV	V	VI	I'	V'	RE	LE
A3	LDL					5.92					
A4	LDL-10					6.12					
A5	LDL-20					6.28					
A6	LDL-30					6.92					

Fig: 1 Responses at different levels depicting the L-I function.

level as shown by steep L-I function of wave V of ABR. The loudness function was similar to normals despite of the presence of hearing loss in cochlear pathology individuals.

2. Slope of the latency-intensity function

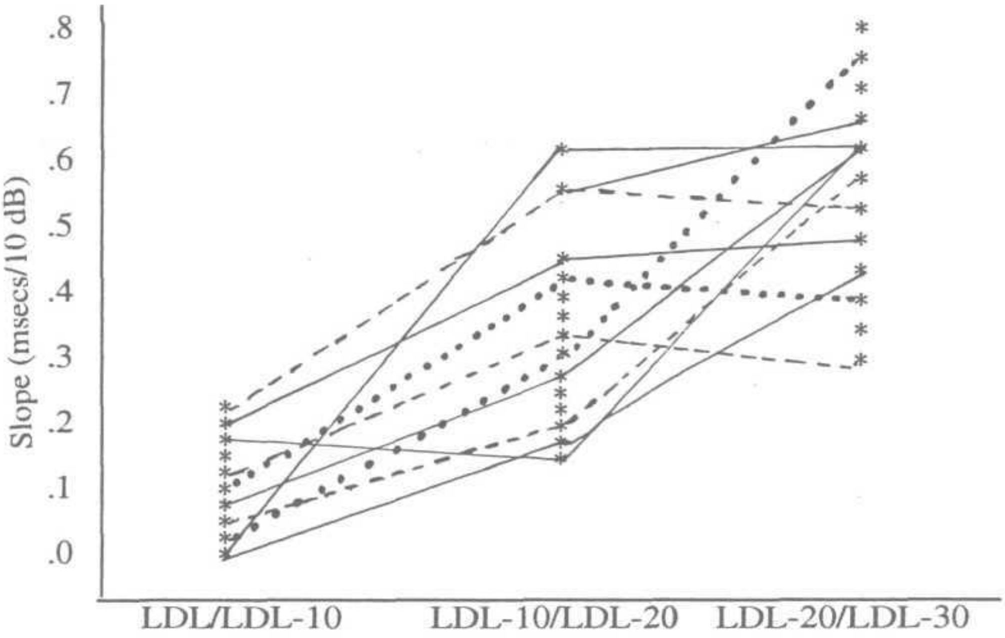
For a few ears, wave V could not be recorded at LDL-30 dB nHL. Hence slope for all 3 levels could be obtained only for 14 ears.

Table-2: Mean wave V slope in msec/10 dB change in level.

Stimulus level	Mean slope of wave V (in msecs/10dB
LDIr(LDL-10)	0.196
(LDL-10)-(LDL-20)	0.29
(LDL-20)-(LDL-30)	0.39

The slope of L-I function at different stimulus level is presented in Table-2. There was a well ordered trend where the slope decreased as LDL was reached, from 0.39/10 dB to 0.19/10 dB. Hall (1991) reported that latency of wave V decreases as a function of the degree of loss and at high intensity levels slope becomes steeper.

Fig.2: Individual curves of wave V slope for 10 dB change in the stimulus level.



Different intensity levels (dB nHL)
at which slope was calculated

The individual functions and each slope was analysed with respect to different levels of stimuli. It can be observed rom Fig.2 that slope was less than 0.2 msec/10 dB (range=oto 0.2 msecs) at the intensity corresponding to LDL/LDL-10 for a majority of the subjects. The slope was more than 0.2 msecs. (range=0.2 msecs to 0.68 msecs) at LDL-20/ LDL-30 level. At the intermediate level,7 individuals had slope lesser than 0.2 msecs and 7 individuals had slope more than 0.2 msecs Hence the slope of the L-I function appeared to be closely related to the LDL. At LDL/LDL-10 level the slope for all subjects was found to be less than 0.2 msecs. Thornton, et al. (1987) reported that the average slope was less than 0.1 msecs at LDL-15 dB in individuals with hearing loss (ranging from 40 to 80 dB HL). In the present study, 0.2 msecs was taken as a reference (criteria) to correlate between slope of L-I function and LDL.

In the present study, for 5 individuals the slope did not reach 0.2 msecs even at LDL level. Out of the five, three subjects had Meneire's disease and their slope was 0.46 at LDLVLDL-10 level. 0.6 at LDL-10/ LDL-20 level, and 0.12 at LDL-20/LDL-30 level. Probably in this kind of cochlear pathology, the cochlear mechanism is disrupted in such a way that loudness growth is not reflected appropriately with L-I function when compared to other cochlear pathologies. But the subjective perception of loudness was similar to that of other subjects i.e. average LDL was 91.6 dB HL despite the presence of hearing loss. This supports the findings of Hood and Poole (1966a) who demonstrated LDL judgements for puretones stimuli to be at approximately equal levels (100-105 dB SPL) in ears with Meneire's disease with hearing loss and ears with normal hearing. It appears that slope of L-I function is not sensitive to the loudness function in Meniere's disease. It has been reported that ABR peak latencies and interpeak latencies are also not good indicators for diagnosis of Meneire's disease (Hall, 1991). Further investigation is required to study the relationship between L-I function and subjective LDL in a large group of subjects with Meneire's disease. For the. other 2 ears, where slop did not reach 0.2 m secs at LDL, nothing could be reasoned out..

3. **Correlation between the LDL and slope of L-I function**

In order to know the degree of relation between intensity at which slope of the L-I function becomes less than 0.2 msecs/10 dB and the subjective LDL for puretones and speech, Pearson's product moment correlation co-efficient was calculated.

Table-3: Correlation co-efficients between slope of L-I function and subjective LDL for different stimuli.

Stimuli (LDL)	Pearson's 'r'
Puretone of 2 kHz	0.201
Puretone of 4 kHz	0.04
Speech	0.608

Inspection of Table-3, showed that there was a good correlation of 0.6 between the intensity level at which the slope was less than 0.2 msecs and LDL for speech. However, correlation between LDL for puretones of 2KHz and 4 kHz and intensity at which slope becomes less than 0.2 msecs was very poor. This might be due to the broad spectrum of speech (Kent, 1992) leading to wide spread of energy (vibratory pattern) across the basillar membrane which is similar to clicks where there is broadening of travelling waves along the basillar membrane leading to wide spread of vibratory pattern (Gelfand, 1981). Whereas for sinusoidal signals, the tuning of the basillar membrane is not as broad as for clicks even at higher intensities. Because of this sharp tuning of basilar membrane for puretones and broader tuning for speech there might be a poorer correlation between LDLs of 2 kHz, 4 kHz and the slope of L-I function, but a good correlation between LDL for speech and the slope of L-I function. This supports the hypothesis of Serpanos, et al.

(1997) that the relationship between subjective loudness and ABR will be affected by the test stimulus used in the study.

Further analysis was carried out with data of speech stimulus only. Probable error of co-efficient was obtained. This coefficient being 0.113 which is less than correlation coefficient (correlation coefficient should be greater than 4 times of probable error) depicted that correlation obtained was significant. Probable error also gives the limits within which correlation coefficient can fall. The obtained correlation coefficient was subjected for an another test of significance i.e. 't'-test and it was found to be significant at 0.05 level, ($t = 2.64$; df :27; P: <0.05 S')

This indicated that it is possible to predict subjective LDL based on L-I function.

4. Prediction of LDL for speech based on slope of L-I function

A regression analysis was carried between measured LDL for speech stimulus and the intensity level of the stimulus at which the slope was less than 0.2 msecs. The following equation was obtained.

$$\mathbf{Y = 0.9\,I + 34}$$

where, Y = Subjective LDL
I = Intensity level of the stimulus at which L-I function slope becomes less than 0.2 msecs
34 = constant
0.9 = regression coefficient of Y on I

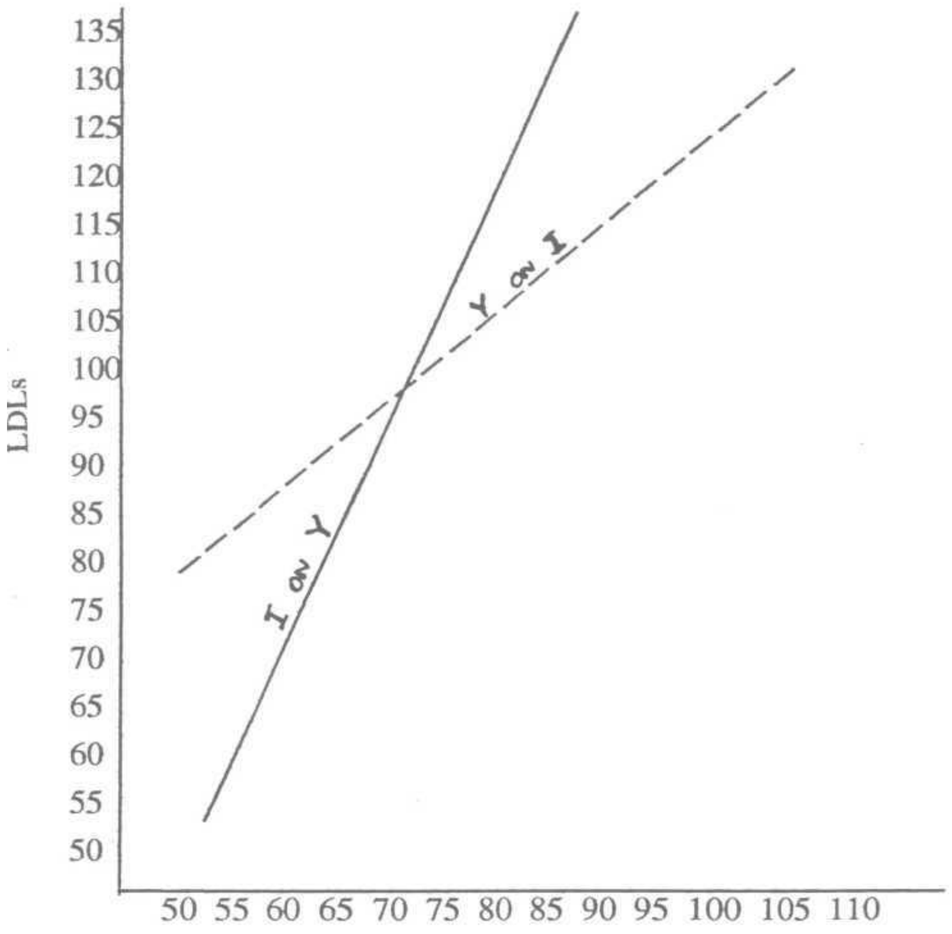
The standard error of estimate of Y values on I was 6.26. That is. the subjective LDL calculated through this equation varies within +/- 6 dB, of the actual LDL.

Coefficient of determinant (cd) was calculated to study the percentage of variance that can be explained. This (cd). was 0.37 and co-efficient of non-determinant was 0.63 i.e. 37% of the variance in the study is explained and the 63% of the variance is not explained.

6. **Determining the strength of regression**

In order to determine the accuracy of regression, in determining the subjective LDLs which are not known from the known slope values, regression curves were drawn. One curve was drawn with intensity levels (where the slope was less than 0.2 msecs) changing in 5 dB nHL steps and the corresponding LDL value as per the regression equation. A linear curve was obtained as shown in Fig.3 (i.e. Y values on I). The other curve was drawn in a reverse fashion with known LDL values and the unknown intensity level at which the slope becomes less than 0.2 msecs. This was done to determine the strength of equation in predicting the values. It can be seen from the Fig.3 that curves intersect each other showing that both variables regress over each other.

Hence there exists a relationship between slope and the loudness discomfort level. Earlier studies have used L-I function for studying loudness growth (Galambos and Hecox, 1977; 1978; Gibson and Ruben, 1978; Picton et al. 1977; Thornton, et al. 1987a; Yamada, et al. 1979).



Click level at which the slope of
wave V is less than .2 msecs.

Fig.2 :Two regression curves obtained for two equations:- Y ON I
I ON Y (REVERSE CURVE)

But these relations or links have been mainly descriptive and were often limited to single case studies of subjects that displayed various degree and configuration of hearing loss. Even wide variations in the psychophysical loudness estimate procedures, stimuli used would have precluded attempts of classifying specific patterns of ABR responses for use in estimating loudness growth in the individual listener, (Galambos and Hecox, 1977, 1978; Picton, et al. 1977; Yamada, et al. 1979).

Thornton, et al. (1987) gave the relationship between the subjective LDL for clicks and I as follows:

Subjective LDL for clicks = I + 15 dB
where. I = Intensity level at which the slope becomes less than 0.1 msecs/10dB.
15 dB = constant

They reported that the same can be used for subjects with different types of hearing loss and configuration of loss. However very few subjects with different configuration of loss were included in then-study. There is evidence in literature that the type (Fowler and Durrant, 1994; Fria,1980) and the configuration of hearing loss (Gorga, et al. 1985; Fowler and Durrant, 1994) has an effect on L-I function slope of wave V. The present study considered only subjects with flat sensorineural hearing loss. There is a need for further investigation to check whether the formula obtained in the present study is applicable for different types and configuration of hearing loss.

The equation given by Thornton, et al. (1987) predicts LDL for clicks. They reported a good correlation between LDL for clicks and LDLs for puretones (2 kHz and 4 kHz). However the results of the present study showed that L-I slope of wave V correlates better with speech when compared to 2 kHz and 4 kHz puretones. Although it is reported that at lower intensity level (threshold level) the ABR threshold correlates with 2 kHz and 4 kHz puretone behavioral thresholds, this was not found at higher intensity levels. It can be inferred from this that ABR at low intensity and that at high intensity are generated by different regions of cochlea.

The results of the study showed that there was a relationship between the slope of L-I function and subjective LDL. Therefore subjective LDL can be predicted from slope of L-I function.

SUMMARY

Loudness discomfort level is one of the important measures which is clinically used. It is used to set the maximum output from the hearing aid, to determine the presence of recruitment, and to perform the suprathreshold tests. As LDL cannot be obtained reliably through subjective methods in young children, difficult-to-test population, and individuals who give inconsistent responses, an objective method is needed to calculate the LDL. Hence the present study was conducted.

The aim of the study was to find out the relation between subjective LDL for speech, puretones of 2KHz and. 4KHz and slope of L-I function of wave V.

Twenty two ears of 18 subjects with flat sensorineural hearing loss ranging from 26 dB HL to 70 dB HL were studied. All the subjects had LDL of less than or equal to 110 dB HL for puretones, speech and clicks.ABR was recorded starting from LDL level to LDL-30 dB nHL level. The slope of L-I function of ware V was calculated.

The obtained L-I function values were analysed and results were as follows:

- The wave V latency values reduced from LDL-30 level to LDL level and reached near normal values which depicted the presence of recruitment-

- The slope also had steeper growth as the intensity level was increased from LDL-30 to LDL level.
- The slope analysis indicated that at a particular level [LDL-(LDL-10)] the slope value was less than 0.2 msecs in majority of subjects.

There was poor correlation between LDL for puretones (2 kHz and 4 kHz) and the intensity level at which this slope value is less than 0.2 msecs. But a good correlation was found between LDL for speech and the intensity level at which the slope value is less than 0.2 msecs. Hence the following regression equation was obtained for predicting speech LDL only.

LDL = 0.9 I + 34

Where, I = intensity level at which the slope is less than 0.2 msecs.
34 = constant
+/- 6 dB = Standard error

This study gives an equation to objectively estimate the LDL for speech through L-I function of wave V. This equation can be used to estimate LDL for the young children, difficult to test population whose LDL cannot be obtained reliably through any other methods.

Limitations/Suggestions

1. LDL can be predicted only for flat sensorineural hearing loss individuals through this equation. Further investigation has to be carried out with different types and configuration of hearing loss.

2. Number of subjects included were less as subjects meeting the criteria were difficult to find within specific time period.

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APPENDIX

Instructions for obtaining LDL for speech.

Berger's (1976)

Now you will hear the speech you heard before, but it will gradually become so loud that it is uncomfortable to you, just say"stop" and I will turn it off. Don't say stop ifyou merely consider the speech distracting, but only when it first becomes uncomfortably loud. If you could not listen to the speech for fifteen minutes or more, then consider it uncomfortable.

McCandless (1973)

The time the speech will gradually become louder and louder, let me know when the sound FIRST becomes annoying or uncomfortable, that is when you could not care to listen to the stimulus for any length of time.