LLR AS A MEASURE OF TEMPORAL INTEGRATION

REGISTER NO. M2K23

An Independent Project submitted in part fulfillment of the
First Year M.Sc, (Speech and Hearing),
University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING,
MANASAGANGOTHRi,
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MAY, 2001

DEDI CATED

TO MY PARENTS

AND

BROTHER

Certificate

This is to certify that this independent project entitled *"LLR as **a measure of temporal integration"*** is the bonafide work done in part fulfillment for the First Year Master of Science (Speech & Hearing) of the student with Register No.M2K23.

Mysore,

May, 2001

Director

All India Institute of

Speech & Hearing,

Mysore -570 006

Certificate

This is to certify that this independent project entitled *"LLR as **a measure of temporal integration"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

Guide

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Declaration

This independent project entitled ***"LLR** as **a measure of temporal integration"*** is the result of my own study under the guidance of Mrs. C.S. Vanaja, Lecturer, Department of Audiology, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier in any other University for the award of any Diploma or Degree.

Mysore, Register No. M2K23

May, 2001.

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Chapter I

INTRODUCTION

The process of auditory perception is a complex auditory processing phenomenon of the interaction between the physical characteristics of the stimuli, its processing with in the nervous system and the psychological response to it. Among the physical characteristics of the stimuli, duration has been found to play a major role in its perception. Since many years it has been known that both absolute thresholds and loudness of sounds depend upon the duration of the stimuli (Exner, 1876, cited in Moore, 1982). For durations up to a few hundred milliseconds, the intensity required for threshold decreases as the duration increases. But for durations exceeding about 500 ms, the sound intensity at threshold is roughly independent of duration (Moore, 1998). This improvement in threshold, with increase in duration indicates that the auditory system has the ability to operate in such a way that time can be traded for intensity in order to maintain a constant signal energy level and relatively constant signal detectability (Eddins and Peterson, 1999). This phenomenon of time intensity trade has been attributed to temporal integration.

Historically, temporal integration has been one of the oldest areas of study. A majority of the studies that have been conducted in this area have used psychophysical methods. Gelfand (1998) summarized the two routinely encountered observations on temporal integration as follows:

1. For durations up to roughly 200-300 msec, a tenfold (decade) increase in duration, i.e., from 20 msec to 200 msec, threshold decreases by about 10 dB.

2. Durations longer than about 300 msec are treated by the ears as though they are infinitely long and hence increasing or decreasing durations beyond this does not cause further change in threshold.

Tests have been developed in the past to evaluate this phenomenon of temporal integration. One such test is brief tone audiometry, which examines the relative threshold difference for tones of various durations. Based on a review of literature on brief tone audiometry, Wright (1978) concluded that subjects with normal hearing, conductive hearing loss and eighth nerve lesion demonstrated an improvement of about 10 dB in threshold when the duration of the signal was increased from 20 msec to 500 msec whereas, the difference was found to be less than 5 dB in subjects with cochlear pathology. Wright (1978) further reported that if improvement in threshold is 15 dB or more, it is audiologic support of temporal lobe dysfunction or pseudohypacusis.

This brief tone audiometry being a behavioral test has inherent subjectivity in it, and requires active participation of the subject. Hence it is not possible to administer this test on difficult-to-test population. In order to overcome the shortcoming of subjective tests more objective electrophysiological tests are being employed to evaluate the functioning of the auditory system. But the literature available regarding studies investigating temporal integration using an objective tool like evoked potential is very less. One of possible reason for this could be that when evoked potential such as brainstem responses were used for evaluating durational effects, no significant changes were found. This could be expected, as brainstem responses are onset responses independent of duration (Gorga, Beauchaine, Reiland, Worthington and Javel, 1984) Hence, if an evoked potential not affected by onset is chosen durational effects can be studied. Long latency response (LLR) is an auditory evoked response, which is dependent on duration of the stimulus but is independent of stimulus onset. Therefore it can be expected that LLR will be affected when duration of stimulus is altered. Results of an investigation by Eddins and Peterson (1999) demonstrated a consistent time-intensity trading relationship in LLR, similar to that observed in psychophysical experiments.

Eddins and Peterson (1999) tried to evaluate the nature of time-intensity trading using LLR by doubling the duration (8, 16, 32, 64, 128 msec) but did not collect data regarding decade increase in duration. If information regarding threshold improvement per tenfold (decade) increase in duration could be made available, with just two data points amount of integration taking place could be found out. This would considerably shorten the time taken for evaluation.

Hence the current study was under taken to investigate the following aims:

1. To compare the latency, amplitude and morphology of LLR waveform for 100 msec and 10 msec stimulus duration.

2. To compare the latency, amplitude and morphology of LLR waveform at 60 dBnHL and at threshold for both the durations.

3. To study the changes in long latency response threshold with decade increase of stimulus duration.

Need for the study:

A review of literature shows that temporal integration helps in differential diagnosis of auditory disorders. Temporal integration has been studied using behavioral measures in the past. However, it may not be possible to administer behavioral tests in some of the difficult-to-test population especially in children with central auditory processing disorders (CAPD). Recent literature shows that LLR can also be used to investigate temporal integration. As LLR does not require any voluntary response from the subject, it would be relatively easier to administer when compared to administration of complex speech tests in evaluating children with CAPD. This test also has an additional advantage in a multilingual country like India, since there is no language barrier. In view of these aspects the present study was undertaken to investigate temporal integration in normal subjects using an electrophysiological measure.

Chapter II

REVIEW OF LITERATURE

The relation between stimulus duration and stimulus intensity in perception of acoustic energy is generally referred to as temporal integration / temporal summation. Temporal integration of acoustic energy describes the increase in sound impression, which is achieved by increasing the stimulus duration but keeping the sound pressure constant (Pedersen and Elberling, 1972a). Brief tone audiometry is a diagnostic audiological test procedure, which is based on this phenomenon of audition - the ability of the ear to accumulate and integrate acoustic energy over a period of time (Sanders and Honig, 1967). During 1960's perception of brief tones had been the subject of increasing interest among many investigators. The reason of this could have been the fact that the perception of brief tones was considered important in discrimination and that brief tone audiometry seemed to have a possibility as a diagnostic tool for it (Pedersen and Elberling, 1972a).

Literature in the past indicates that a number of investigations have been carried out on both normal and pathological subjects to study temporal integration. A majority of the psychophysical methods such as method of adjustment, limits, constant stimuli, signal detection paradigms have been used to study temporal integration (Olsen, 1987). Pedersen and Elberling (1972b) have reviewed some of the different investigations to measure temporal integration and classified the various methods as follows:

1. Tracing by Bekesy audiometry (Wright, 1969; Olsen and Cornell, 1972; and Rose, 1972).
2. Method of limits (Dallos and Olsen, 1964).

3. Method of adjustment (Watson and Gengel, 1969).
4. Response to just perceptible signal (Miskolczy-Fodor, 1960; and Pedersen and Elberling, 1972).

A review of literature indicates that a majority of the studies investigating the clinical application of brief tone audiometry in the past have used Bekesy threshold tracking procedure. Temporal integration has been reported for one of the following or a combination of these measures:

a. Decade change in duration of brief tone signal (Sanders and Honig, 1967; Hattler and Northern, 1970; Martin and Wofford, 1970; Florentine, Fasti and Buus, 1988).
b. Doubling of duration of a brief tone signal (Pedersen and Elberling, 1972a).
c. Time constant or critical duration (To) beyond which no further improvement in threshold could be seen (Sanders and Honig, 1967).

Investigators have also studied the effect of different factors such as frequency and intensity on temporal integration. Review of studies on temporal integration are discussed in this chapter under the following sections:

I. Studies on normal hearing subjects.
II. Studies on clinical population.

/. STUDIES ON NORMAL HEARING SUBJECTS.

Sanders and Honig (1967) gathered normative data for the slope of integration in ten normal hearing subjects. The stimulus used had a rise and fall time of 10 msec with duration ranging over 200 msec at 250 Hz, 1 kHz and 4 kHz. Threshold determination was done using Hughson-Westlake ascending method in 1 dB steps. The results revealed that T_o (Critical duration) was close to 150 msec at each frequency. The mean threshold at T_o varied as a function of frequency (~ 10 dB at 1 kHz and 4 kHz; ~ 30 dB at 250 Hz) but the slope remained constant (~ 10 dB / decade) with a linear function. Similar results for decade increase in durations were also reported by other investigators (Hattler and Northern, 1970; Martin and Wofford, 1970; Sanders, Josey and Kemker, 1971).

Pedersen and Elberling (1972a) provided normative data for both decade increase and doubling of stimulus duration for octave frequencies from 500 Hz to 8 kHz. Stimulus duration varied from 1 msec to 1000 msec (1, 2, 5, 10, 20, 50, 100, 200, 500, 1000). The rise and fall time varied depending on frequencies (e.g., 500 Hz- 4 msec, 1 kHz- 2 msec, 2 kHz- 3 msec, 4 kHz- 3.5 msec, 8 kHz- 1.75 msec). The results indicated that the slopes i.e., dB change in threshold per decade change in duration, was 11.1 at 500Hz and 8.1 at 8kHz. The results also indicated that for stimulus durations below 200 msec the amplitude of stimulus must be increased by about 3 dB, when time is halved.

In a subsequent study, Pedersen and Elberling (1972b) investigated the slope of integration for ten different tone pulse durations with rise time of 2 msec, 14 msec and a tone burst at 1 kHz passed through a $1/3^{rd}$ octave filter. It was observed that the rise time of the signal does not affect the slope of integration in normal subjects. However, they found that the temporal integration for $1/3^{rd}$ octave filtered tone burst was slightly reduced. Results of an investigation by Florentine, Fasti and Buus (1988) using two interval, two alternative forced-choice paradigm with feedback reported an improvement in threshold upto a maximum duration of 500 msec. They have also reported a slope of about 7-8 dB / decade, which is similar to earlier findings.

Variability in results of temporal integration

Sanders and Honig (1967) observed large standard deviation for To. which indicates wide variability of T0 in normal ears. Richards and Duun (1974) also noted wide variability in the slope for temporal integration across normal hearing subjects. The difference in threshold between 20 and 200 msec duration tones for five normal hearing subjects was 4 dB or less which overlapped with the values usually proposed for hearing impaired listeners. Only three subjects produced integration slopes of 8 dB or greater and the remaining had a slope between 4-8 dB. These results indicate the need for continued investigation of variability of individual temporal integration functions in normal and abnormal listeners.

Gengel and Watson (1971) also recommended the necessity of repeated measurements to obtain a reliable estimate of temporal integration measures. However, Pedersen and Elberling (1972b) have reported high test-retest reliability for temporal integration measured with one day and one-year interval. Attempts have been made to study the factors, which affect temporal integration. Some of the variables that have been studied include frequency and intensity of the stimulus.

Effect of frequency on temporal integration

A number of studies have reported that the slope of temporal integration is not the same for different frequencies. Pedersen and Elberling (1972a) found a decrease in the slope of temporal integration as a function of frequency. They found a systematic decrease when the frequency was varied from 500 Hz to 8 kHz with a slope of 11.1 dB at 500 Hz and 8.1 dB at 8 kHz. Similar results were also obtained by other investigators (Hattler and Northern, 1970; Sanders, Josey and Kemker, 1971; Gengel and Watson, 1971; Florentine, Fasti and Buus, 1988). As the slope of integration was shallower at high frequencies when compared to lower frequencies, it was concluded that the temporal integration is less efficient at higher frequencies than at lower frequencies (Gengel and Watson, 1971) However, Barry and Larson (1974) showed a mean threshold difference of about 10 dB between 20 msec and 500 msec tone, for all the four frequencies tested (500 Hz, 1 kHz, 2 kHz and 4 kHz). The reason for these differences in findings is not clear.

Martin and Wofford (1970) made an interesting observation in normal hearing subjects. A study of pattern of temporal integration across frequencies 250 Hz to 8 kHz showed a notch at 4 kHz, which was similar to audiogram pattern in subjects with noise induced hearing loss. Hence the probability of a sub clinical lesion in the cochlea of normal subjects was suggested. Wright (1978) also supported this notion and suggested that brief tone audiometry was extremely sensitive to cochlear lesions that commonly manifested at higher frequencies. Hence, sub clinical lesions not of handicapping significance could be the cause for the frequency effect observed.

Thus, some investigators report that frequency has an effect on temporal integration whereas others maintain that such frequency effect is not observed in 'true' normal subjects but it is due to extreme sensitivity of brief tone audiometry to sub clinical cochlear lesions also. Wright (1978) attributes this discrepancy between results of the two groups to different methodologies used.

Effect of intensity on temporal integration

To study the effect of intensity, temporal integration has been studied at threshold and supra threshold levels. Stelmachowicz and Seewald (1977) studied pure tone thresholds and acoustic reflex thresholds for 500 Hz, 1 kHz and 2 kHz tones of 500, 250 and 25 msec durations with a rise-fall time of 10 msec. Results revealed that supra threshold slopes approximated those obtained at auditory threshold, for subjects with normal hearing.

Summary:

Thus, to summarize, the results of various investigations have repeatedly confirmed the presence of temporal integration in the auditory processing mechanism. In a normal ear, if the duration of a signal is reduced below 200 msec, an increase in intensity is required to maintain audibility. Intensity should be increased by about 8-10 dB, if the duration is decreased by a factor of 10 or by 3 dB if the duration is halved. Apart from this, it is also found that as frequency increases the efficiency of integration decreases and the slope becomes shallower. However, no difference in temporal integration is found at threshold and supra threshold levels.

II. *STUDIES ON CLINICAL POPULATION.*

A majority of the investigations have focused on temporal integration in subjects with cochlear pathology as temporal integration occurs at the level of cochlea (Wright, 1968). A few researchers have also conducted studies on patients with retrocochlear pathology, conductive hearing loss and temporal lobe dysfunction.

1. *Cochlear pathology.*

Results on subjects with cochlear pathology have revealed a reduced capacity to integrate energy over time. Hence the slope of improvement of temporal integration will be much less than that in ears with normal hearing. Sanders and Honig (1967) have observed that brief tone audiometry clearly distinguished an ear with normal hearing from that with cochlear pathology. Also the degree of abnormality in integration of energy tended to be proportional to the magnitude of hearing loss. But no relationship was found between different etiologies of cochlear pathology (e.g., Ototoxicity, Meneiers disease, Presbycusis) and pattern or degree of temporal integration.

Wright (1968), in one of the earliest studies, measured temporal integration at threshold of audibility using Bekesy tracking method. The results obtained from a listener with unilateral moderate sensorineural hearing loss revealed a deviant threshold-duration function in the affected ear. The results were attributed to the physiologic disturbance, probably resulting in excess adaptation, at the level of cochlea, which would result in disruption of normal threshold-duration function. Such disruptions could occur even when the more central physiologic processes responsible for temporal summation were functioning in a normal manner.

Martin and Wofford (1970) also obtained similar results on twelve normal hearing and twelve cochlear impaired adults using fixed frequency Bekesy tracings. Pure tone pulses at octaves from 250 Hz to 8 kHz, with durations ranging from 20 to 500 msec with 10 msec rise-fall time and 500 msec off-time, were used as stimuli. There was a significant difference between temporal integration of the two groups. The cochlear impaired subjects yielded much smaller mean values of 1.8 and 1.3 dB respectively at 4 and 8 kHz. The patients exhibited significant and markedly smaller threshold differences at the higher than lower frequencies. This was attributed to greater loss at higher frequencies. However, the results also indicated overlap between the two groups.

Similar results were reported by Sanders, Josey and Kemker (1971) based on evaluation of ten patients with cochlear pathology, for seven stimulus durations ranging from 10 msec to 150 msec, at 1 kHz and 4 kHz. The slope of integration ranged from 1 to 4 dB at 1 kHz and 2 to 4 dB at 4 kHz, which was consistently less than the slopes for normal ears which had a mean slope of 10 dB at 1 kHz and 8.5 dB at 4 kHz in same stimulus conditions.

Pedersen and Elberling (1973) studied the slope of temporal integration as a function of hearing loss. It was observed that the slope decreased as the degree of hearing loss increased. They measured temporal integration at 500 Hz, 1 kHz, 4 kHz and 8 kHz in forty-six subjects with presbyacusis for stimulus of ten durations ranging from 2 msec to 1000 msec. Analysis of the data also revealed that among the different expressions of temporal integration, most relevant was $-A^2/2B$. This is the area of triangle formed by the abscissa axis, the ordinate axis and the regression line.

Results of an investigation on twenty five patients with acoustic trauma for ten durations ranging from 1000 msec to 1 msec by Pedersen (1973) also revealed correlation between temporal integration and pure tone threshold. The frequencies tested included those with thresholds in normal limits and those with increased threshold. It was observed that temporal integration was reduced in patients with acoustic trauma, and also amount of integration decreased as the hearing loss increased. Temporal integration was affected for frequencies with abnormal pure tone thresholds but was normal for frequencies with normal pure tone thresholds. Correlating these results with the localized hair cell degeneration in acoustic trauma patients, it has been speculated that intact outer hair cells are necessary for normal temporal integration of acoustic energy. Similar results were also reported by other investigators (Chung and Smith, 1980; Florentine, Fasti and Buus, 1988).

Temporal integration in different modalities has also been compared. Gengle and Watson (1971) evaluated 8 hearing impaired subjects for temporal integration from 250 Hz to 4 kHz at octave intervals for durations of 512, 64 and 32 msec. The average difference between thresholds for 32 and 64 msec signals, relative to threshold for a 512 msec signal was calculated. The results revealed that temporal integration was reduced at frequencies with abnormal threshold. For two severely hearing impaired subjects, temporal integration was evaluated in both auditory and tactile mode. The results were similar for both the modes suggesting that in severely hearing impaired subjects tactile stimulation may be controlling threshold response.

The influence of audiometric configuration on temporal integration in cochlear impaired subjects was evaluated by Hattler and Northern (1970). Temporal integration in quite and ipsilateral masking conditions was examined in twenty cochlear-impaired subjects with sloping and flat audiometric configurations. Stimulus duration ranged from 10 to 300 msec with rise fall-time of 2.5 msec. The pattern of temporal integration was found to be clinically reliable and virtually unaffected by audiometric configuration. The threshold changes per log unit of stimulus duration time were found to be essentially the same under quite or ipsilateral masking conditions.

Temporal integration in patients with cochlear pathology was viewed from a different dimension by Pederson and Salomon (1977), by comparing size of temporal integration at threshold and higher sensation level. Temporal integration at higher sensation level, also called loudness summation, was performed by establishing the intensity of pulses which results in equal loudness. It was observed that temporal integration at higher sensation level was reduced in normal subjects similar to that observed at threshold in subjects with cochlear pathology. Hence it was concluded that temporal integration depends on the sound pressure level reaching the cochlea and not on the degree of hearing loss.

Selmachomicz and Seewald (1977) investigated the threshold and supra threshold integration function in cochlear impaired subjects using auditory and acoustic threshold. The results revealed that a significantly steeper threshold-duration function at acoustic reflex threshold than at auditory threshold level where the function was flatter. At supra threshold levels similar threshold-duration function was found in cochlear impaired and normal ears. An investigation by Chung and Smith (1980) using masking to evaluate temporal integration in subjects with noise induced hearing loss at supra threshold levels yielded similar findings.

Thus, it can be seen from this review of literature that cochlear impairment has a definite effect on temporal integration. Temporal integration is usually found to be reduced compared to that in normal ears. Results also revealed a correlation between, degree of hearing loss and reduced temporal integration function.

2. *Eighth nerve lesion.*

Temporal integration is reported to be normal in pathology, which affects only the auditory nerve. Brief tone audiometry has been used in differential diagnosis of cochlear pathology and retrocochlear pathology. Sanders, Josey and Kemker (1971) evaluated temporal integration for 1 kHz and 4 kHz tone in three patients with eighth nerve tumors and in patients with cochlear pathology. Stimulus duration ranged from 150 msec to 10 msec with 5 msec rise-decay time. The results revealed that brief tone audiometry provides a clear distinction between patients with eighth nerve tumor, who essentially have normal integration function and those with cochlear pathology.

3. Temporal lobe dysfunction.

Temporal integration has been studied in patients with temporal lobe lesion as processing of short duration signals in affected by cortical lesions. It has been reported that the detection of short-duration tones (< 10 msec) were affected in ear contralateral to the side of temporal lobe dysfunction in contrast to cochlear pathology where processing of long-duration tones are affected (Gersuni, 1971; Baru and Karaseva, 1972, cited in Wright, 1978). Dean in 1974 (cited in Wright, 1978) administered brief tone audiometry on a few patients with presumptive lesions of the left temporal lobe. The results revealed that the threshold for short-duration tones in the ear contralateral to the side of the lesion was affected while was normal for ipsilateral side. Cranford, Stream, Rye and Slade (1982) tested seven patients with damage in Heschl's gyrus and three with unilateral damage confined to areas outside the parietotemporal region. All the patients were initially tested with standard audiometric examination after which absolute detection thresholds and difference limen frequency were determined for 1 kHz tones of 500, 200, 100, 50, 20, 10 and 5 msec duration with a rise-fall time of 1 msec. The results indicated that thresholds for brief tones may be elevated in the case of temporal lobe lesion. These findings were found to reduce in magnitude with time following cerebral insult. It was concluded that the brief tone tests may function as a form of stress test in a manner analogous to the degraded speech tests. However, for this rather than standard temporal integration tests, tests for frequency limens using brief tones was suggested.

Jerger, Lovermg and Wertz (1972) studied temporal integration in a patient with bilateral temporal lobe lesion. They reported threshold-duration function for 1 kHz tones with durations ranging from 25 to 2000 msec. Elevated temporal integration function was observed in both ears. For signals of very short durations, the intensity of sound had to be appreciably (20-25 dB) raised to maintain threshold response in subjects with temporal lobe lesion. Whereas normal subjects had threshold of less than 10 dB.

Thompson and Abel (1992) studied the effects of anatomical site of lesion on the processing of intensity, duration and frequencies cues. They used as a two-alternative, forced choice procedure. They studied duration, detection and discrimination for tones of 50 msec and 300 msec duration with rise-fall times of 10 msec at 500 Hz and 2 kHz. Groups of subjects comprising cochlear, eighth nerve, cortical lesions and normals were included in the study. The results indicated that the group with left temporal lesions exhibited the greatest deficits in processing all three acoustic parameters. Also a majority of the subjects had a better detection threshold for the longest stimulus. For left temporal pathology a significant elevation in detection threshold in the contralateral ear was found which was not evident from routine audiometry. The detection thresholds observed for the right temporal pathology group was poorer than that of normal subjects but better than that of subjects with left temporal pathology. However, the differences in threshold were not statistically significant. The speech intelligibility scores were also poorer in subjects with left temporal lobe and correlated significantly with the detection threshold for short duration signal.

Thus, it can be inferred from the results of various investigations that the processing of temporal aspects (especially brief signal durations) would be affected in patients with temporal lobe dysfunction. This would result in an increase in the slope of temporal integration.

4. *Conductive and mixed hearing losses.*

Studies on patients with conductive loss have revealed integration functions similar to that found in normal hearing subjects. This can be expected as cochlea, which is thought to be responsible for temporal integration is intact in conductive pathology. Wright and Cannella (1969) obtained tracings for thresholds for stimulus of durations ranging from 500 to 10 msec with a rise-fall time of 10 msec at 250 Hz, 1 kHz and 4 kHz. They selected a group of normal hearing listeners who were temporarily induced conductive hearing loss by deep insertion of a vaseline gauze plug in to the external auditory meatus. Brief tone audiometry was administered before and after as well as in the presence of induced conductive loss of about 40dB. The results revealed no difference among the three conditions, there by substantiating that a conductive hearing loss has no effect on temporal integration. They also verified the results in a young patient who presented with a mild conductive hearing loss where the brief tone audiometry results did not change pre and post treatment with decongestants. In subjects with mixed loss, it was found that only sensory neural component accounted for the deviant results. Similar results were also obtained by Florentine, Fasti and Buus (1988) who studied simulated impairments.

Thus a review of literature reveals that a host of investigations have been conducted to study temporal integration phenomenon in both normal and clinical population using psychophysical methods. Results reveal that in pathologies where cochlea is involved temporal integration function is found to be deviant whereas, in pathologies such as eighth nerve tumor or conductive pathology, temporal integration is normal, suggesting a differential effect of temporal integration phenomenon. In patients with temporal lobe dysfunction, the slope of temporal integration will be larger than that in normal as processing of short duration signals will be affected in them.

A few attempts have also been made to check if a similar threshold-duration trading function can be examined using auditory evoked potentials. Therefore a number of investigations have been conducted to explore the effects of stimulus duration or rise-fall time on both latency and amplitude measures of evoked potential components. But relatively very few studies illustrate the variation in evoked potential threshold with duration.

Hecox, Squires and Galambos (1976) studied auditory brainstem response (ABR) elicited by bursts of white noise. It was observed that the latency and amplitude of the ABR are established exclusively by the stimulus rise time but not by fall time or its duration. Similar results were also reported by other investigators (Hecox and Deegan, 1983; Salt and Thornton, 1984; Suzuki and Horiuchi, 1981; Kodera, Hink, Yamada and Suzuki, 1979). Effects of stimulus duration on ABR and behavioral thresholds for three normal and two hearing impaired subjects, was evaluated by Gorga, Beauchaine, Reiland, Worthington and Javel (1984). Though normal subjects showed greater improvement in behavioral thresholds as a function of duration than did subjects with hearing loss ABR thresholds were found to be independent of stimulus duration in both groups. These results suggest that duration effects on threshold cannot be studied using ABR. Vivion, Hirsch, Frye-Osier and Goldstein (1980) demonstrated an increase in latency and decrease in amplitude of middle latency response (MLR) components as the rise-fall time increased from 3-10 msec or plateau duration was increased from 10-30 msec.

Koendra, Hink, Yamada and Suzuki (1979) studied the effect of rise-time on ABR, MLR and LLR. Stimuli consisted of 1 kHz tone bursts with total duration of 42 msec. Two stimulus rise times of 5 msec (5-32-5) and 20 msec (20-2-20) was used to study the effect of rise-time. Results showed the increase in rise-time to be associated with smaller peak amplitude (which was not significant for LLR) and longer peak latencies for all evoked potential components measured. It can be observed from the methodology that when the rise-time was increased in the experiment, there was a decrease in the plateau. Therefore the results need to be interpreted with caution. It is not clear whether the change in amplitude and latency was due to increase in rise-time and decrease in plateau time. It is possible that the early potentials were affected by the rise-time where as the late potentials were affected by the duration of the plateau. Studies on LLR have also reported an interaction between effects of rise-time or plateau duration of signal. Onishi and Davis (1968) using 1 kHz tone bursts demonstrated that latency of Nl and amplitude of N1-P2 complex decreased as plateau duration increased from 0-30msec with rise-time of 3msec. However, with rise-time of 30 msec amplitude and latency did not change when plateau was varied from 0-300 msec. Similarly Skinner and Jones (1968) found decrease in P1 latency with increase in plateau duration, but no consistent change in amplitude was found.

Thus it can be seen that a majority of the studies on auditory evoked potentials have investigated the effect of stimulus characteristics on the latency and amplitude of the potentials. The results consistently show that ABR is affected by rise-time and LLR is affected more by duration of the plateau. Hence LLR can be used to investigate the time-intensity trading relationship similar to that studied using psychophysical methods. One such attempt was made by Eddins and Pederson (1999). LLR thresholds were traced for stimuli durations of 8, 16, 32, 64, 128 msec with 4 msec rise-fall time. The results demonstrated that LLR threshold decreased as duration increased. These results were found to be similar to psychophysical data demonstrating a consistent time-intensity trading relationship. It was concluded that LLR can be used as a tool to evaluate temporal integration. Psychophysical studies have reported difference in threshold for decade change in duration along with doubling. But in the literature there is no data regarding decade change in duration using electrophysiological methods (LLR). Hence, the present study was a step in that direction.

Chapter III

METHEDOLOGY

1. SUBJECTS

Twenty subjects, ten males and ten females, in the age group of 18-22 years were selected for the study. All subjects had normal hearing sensitivity with no history of any otological or audiological problems.

2. INSTRUMENTS

- A calibrated audiometer Madsen OB822 with TDH-39 ear phones lodged in MX-41/AR ear cushions.
- A calibrated immitance meter,GSI-33, (version 1) middle ear analyzer.
- Nicolet bravo evoked potential system (version 1.5) with TDH-39P ear phones in MX-41/AR ear cushions and silver coated disc type electrodes.

3. DATA COLLECTION.

a. Hearing screening:

All the subjects were screened to ensure that they have normal hearing with thresholds equal to or less-than 15 dBHL at octave frequencies from 250 Hz i©8 kHz. This was followed by immittance screening to rule out any middle ear pathology.

b. Electrophysiological testing.

1. Instructions

Subjects were instructed to sit comfortably on the chair and relax. They were instructed that they will hear the sounds in one ear only and that no voluntary response was required. Subjects were told to be alert during the test period and not to fall asleep. They were asked to avoid extraneous movements of head, neck, jaw for the duration of testing. Instructions were given to the subject in a language familiar to them.

2. **Patient preparation and electrode placement.**

Two channel recording was carried out with non-inverting electrode on the vertex (Cz), inverting electrodes on the mastoids (M1 and M2) and a common electrode on forehead (Fz). The electrode sites were cleaned by rubbing the surface with cotton dipped in rectified spirit and using skin preparing paste. Appropriate amount of gel was used to stick the electrodes in their respective positions. They were secured in their place by a piece of plaster. It was ensured that the impedance at all electrode sites was < 5 kOhm and inter electrode impedance was < 2 kOhm. Earphones were then placed without dislodging the electrodes. Earphones diaphragm was placed directly over the ear canal so that accurate stimulus intensity levels were delivered to the ears.

3. Procedure and analysis

Using the protocol given in Table 1 long latency response was recorded for stimulus of two durations. Initially testing was done at 60dBnHL (Ref: 0 dBnHL = 25 dBSPL). The threshold was established by varying the stimulus in 5dB steps. From the responses recorded P1, Nl, P2, N2 were identified by considering the maximum peak negativity / positivity or midpoint. The lowest level at which Nl or P2 could be recognized was considered as LLR threshold. Average improvement in threshold on decade duration change was found out by subtracting the two threshold values.

***Table 1:* Protocol used for testing LLR.**

Stimulus type	Tone bursts
Stimulus polarity	Alternating
Stimulus rate	1.1/sec
Stimulus frequency	1kHz
Stimulus duration	• 10 msec & 100 msec • Rise time = Fall time = 4 msec • Blackmann's window
Electrode montage	• Non-inverting - Cz • Common - Fz • Inverting - M1&M2
Filter setting	1 Hz-30 Hz
Number of averages	300
Sampling duration	500 msec

Chapter IV

RESULTS AND DISCUSSION

The present study aimed at evaluating the effect of two stimulus durations (100 msec and 10 msec) on LLR threshold. LLR waveform was recorded at 60 dBnHL and threshold was estimated for both stimulus durations. The data obtained was subjected to statistical analysis to investigate the following aims:

- Difference in LLR threshold for the two stimulus durations.
- Changes in peak latency and amplitude of LLR waveform as a function of duration (100 msec versus 10 msec) and intensity (60 dBnHL versus threshold).

Statistical analysis was carried out using NCSS (Number Crunching Statistical Software) version 5X series (Hintze, 1982-1992). Mean and standard deviation (S.D) was calculated for the latency of P1, Nl, P2 and N1-P2 amplitude at 60 dBnHL and latency of Nl at threshold. Significance of difference in the data was analyzed using Wilcoxon' s test for matched pair.

A. LLR threshold for 100 msec and 10 msec stimulus duration.

Late potential thresholds were obtained for 100 msec and 10 msec stimulus durations. Threshold was defined as the lowest level at which a repeatable Nl or P2 was identified. It was observed that the threshold for 100 msec stimulus was better than that for 10 msec. Table 2 summarizes the late potential thresholds for 100 msec and 10 msec stimulus.

Table 2: LLR thresholds for 100 msec and 10 msec stimulus.

Threshold (dBnHL)	Mean (dBnHL)	Standard deviation	Minimum threshold	Maximum threshold
100 msec	11	4.89	5	25
10 msec	26	6.44	15	40

It can be observed from the table that the mean threshold for twenty subjects for 100msec stimulus was 11 dBnHL and 26 dBnHL for 10 msec stimulus. There was a significant difference between the thresholds for both the durations [Probability level (P.L): 0.0001]. The difference in thresholds for 10 msec and 100 msec was calculated for each subject. Means and S.D for threshold difference is summarized in Table 3.

Table 3: Difference in LLR threshold for 100 msec and 10 msec stimulus.

	Mean (dB)	Standard deviation	Minimum threshold	Maximum threshold
Difference in threshold	15	5.477	10	30

As shown in Table 3 the mean difference was 15 dB. Only one subject had an improvement of about 30 dB and another subject showed an improvement of 25 dB. Improvement in rest of the subjects ranged between 10 dB to 20 dB. There was no statistically significant difference in the improvement of threshold as a function of duration between males and females. There was also no statistically significant difference between temporal integration in right versus left ear.

From the results, it can thus be inferred that as the duration of the stimulus was increased there was a significant decrease in threshold. This improvement in threshold as the stimulus duration is increased is consistent with the results of psychophysical studies (Sanders and Honig, 1967; Martin and Wofford, 1970; Hattler and Northern, 1970; Sanders, 1971; Pedersen and Elberling, 1972a, Florentine, Fasti and Buus, 1988) and electrophysiological study (Eddins and Pederson, 1999) which also have found similar time-intensity trading relationship. The results of the present study suggested that there was about 15 dB improvement in threshold with decade increment in duration. The results obtained here for decade increase in duration are slightly more than that previously reported in psychophysical studies, which is generally about 10 dB (Sanders and Honig, 1967; Pedersen and Elberling, 1972a; Florentine, Fasti and Buus, 1988). This discrepancy found could probably be attributed to the methodological differences. In the present study 5dB step was used for threshold estimation, whereas in psychophysical studies smaller steps (lor 2dB) are commonly used. However, it is not feasible to use such small steps during electrophysiological testing due to time constraints. Even Eddins and Peterson (1999) found steeper slope for doubling of duration than that obtained in psychophysical studies (Pedersen and Elberling, 1972a). They have found an improvement of about 24 dB as duration was increased from 8 to 128 msec at 1 kHz with a slope of about 6dB for doubling of duration whereas psychophysical studies report 3 dB increment when the duration is halved (Pedersen and Elberling, 1972a).

B. LLR waveform for 100 msec stimulus duration.

The waveforms forlOO msec stimulus at 60 dBnHL and threshold were analyzed. The latency of all the identifiable components and N1-P2 amplitude were measured.

Wave morphology:

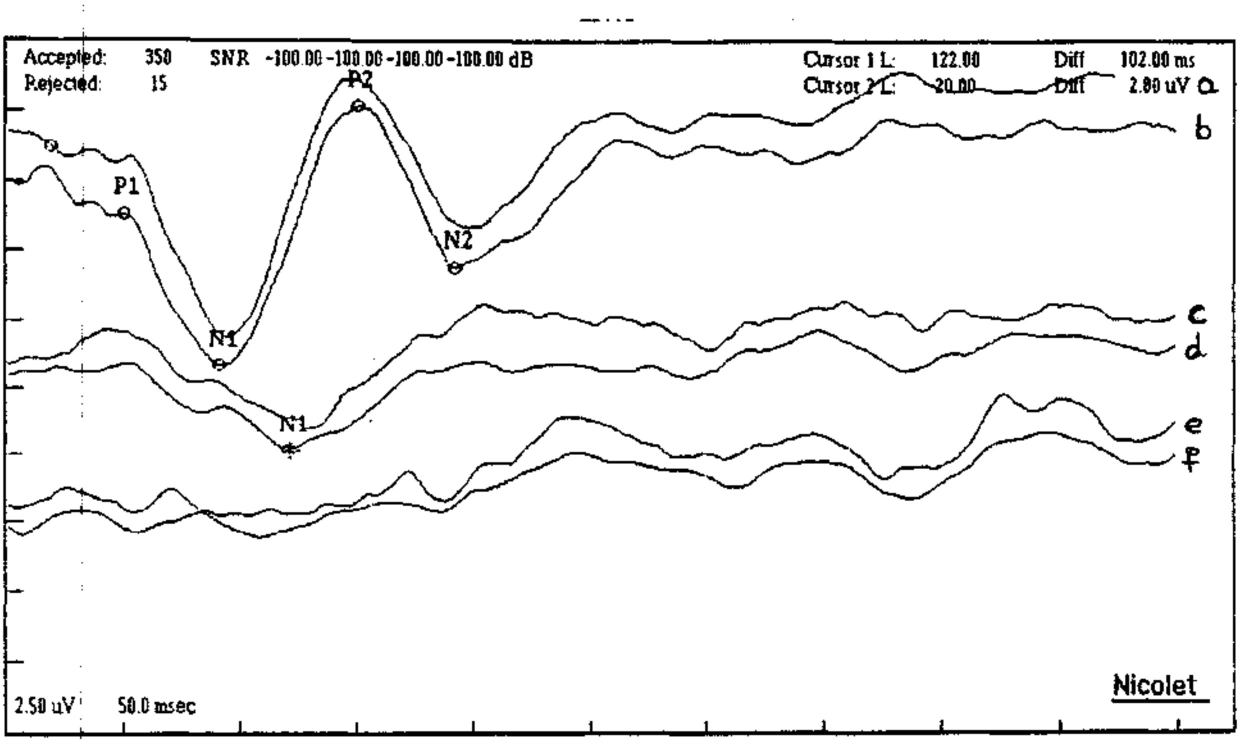
The morphology of the waveform was clear for 100 msec duration than for 10 msec. At 60 dBnHL except P1 all the other components of LLR could be identified in all the subjects. P1 was present in only 12 out of 20 subjects tested. This is consistent with literature, which reports that P1 is least consistent of all the response components (Hall, 1992). P2 was found to be variable in morphology. It was well defined in some subjects whereas it was either broad or bifid in other subjects. This variability in morphology of P2 was also reported by Hall (1992). According to him even in normal hearing subjects P2 may be broad with multiple peaks. It was further observed that the morphology of the waves recorded from the left ear was poor compared to that of the right ear.

Figure 1 illustrates the LLR waveforms at different intensities of a subject for 100 msec stimulus. With decrease in intensity, the amplitude of the waves 'reduced and latency increased. In a majority of the subjects Nl was the only late potential component that could be identified at threshold. N1-P2 complex has been reported as the most robust component, which is observed very close to threshold (Mcpherson, 1996). Eddins and Peterson (1999) have also reported that Nl was the only LLR component identified in majority of the subjects at threshold.

Wave latency and amplitude:

Table 4 summarizes the mean and standard deviation of latency and amplitude of LLR components for 100 msec stimulus at 60 dBnHL. Latency was measured at mid point if a wave was broad. For bifid waves, average of the two peaks was considered as peak latency. Amplitude was measured from trough of Nl to peak of P2.

Figure 1: LLR waveforms at different intensities for 100 msec stimulus.



a & b : Ipsilateral and contralateral LLR waveforms at 60 dBnHL for 100 msec stimulus.

c & d: Ipsilateral and contralateral LLR waveforms at threshold for 100 msec stimulus.

e& f: Ipsilateral and contralateral LLR waveforms below threshold for 100 msec stimulus.

Table 4: Latency and amplitude of LLR components for 100 msec stimulus.

	P1 (msec)	**Nl(msec)**	P2 (msec)	N2 (msec)	N1-P2 (uV)
Mean	59.84	98.35	160.95	221.4	6.8895
S.D	2.57	6.8	10.75	15.95	2.27
N (number of subjects)	12	20	20	20	20

These results of latency and amplitude measures of LLR components at 60 dBnHL are consistent with that reported in literature (Hall, 1992; McPherson and Starr, 1993, cited in McPherson, 1996; Shankar, 1997). At threshold the mean latency of Nl was 131.95 msec (S.D: 16.94). The difference between the latency of Nl at 60 dBnHL and at threshold was statistically significant (P.L: 0.0001). This increase in latency with decrease in intensity (from 60 dBnHL to threshold) was well an expected finding as many investigators have reported such a phenomenon in the past (Adler and Adler, 1989; McCandless and Best, 1966; McCandless and Lentz, 1968; Onshi and Davis, 1968; Rose and Ruhm, 1966). In the present study, the variability was also found to be high near threshold with a greater S.D value (16.94) when compared to S.D of 6.8 at 60 dBnHL. Literature also indicates that when compared to supra threshold level (about 40 dBnHL or higher) near threshold the variability of response latency is higher (Hall, 1992).

C. *LLR waveform for 10 msec stimulus duration.*

Waveform morphology, latency and amplitude components were studied when the duration of the stimulus used was decreased by one tenth i.e., 10 msec. Analysis was again carried out for waveforms obtained at 60 dBnHL and at threshold. The waveforms obtained for 10 msec stimulus duration are as shown in the Figure 2.

Wave morphology:

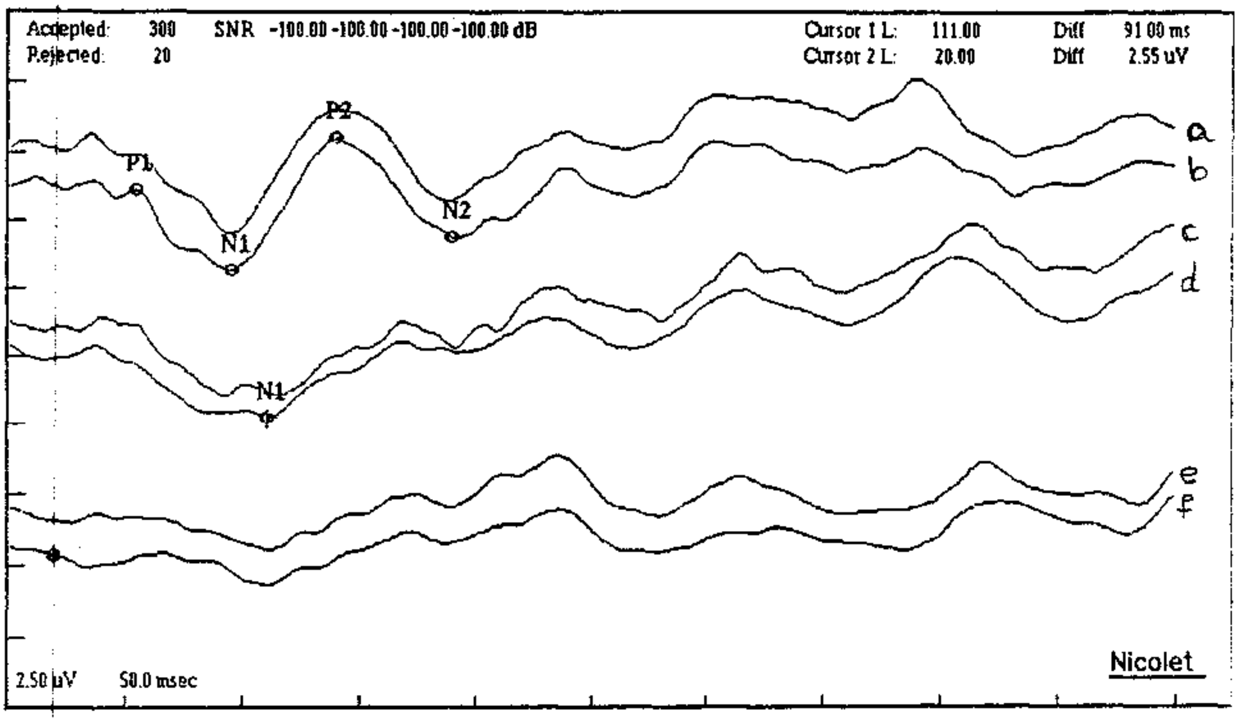
As the duration of the stimulus decreased the wave morphology was found to be generally poor at both 60 dBnHL and at threshold. Even for 10 msec stimulus, a majority of LLR components were identifiable at 60 dBnHL but at threshold only Nl was obtained. Similar to the waveform for 100 msec at 60 dBnHL, P1 was identifiable in only 12 of 20 subjects. Even for short duration signal, it was observed that the morphology of the waves recorded from the left ear was poor compared to that of the right ear.

Wave latency and amplitude:

Inspection of Table 5 reveals that for 10 msec stimulus the latency of the peaks were prolonged compared to 100 msec and amplitude increased. Figure 2 represents LLR waveforms for 100 msec and 10 msec at 60 dBnHL. Hence with decrease in duration an increase in latency and significant reduction in N1-P2 amplitude was found consistent with findings of Onishi and Davis (1968) and Eddins and Peterson (1999). However, decrease in latency was not statistically significant.

The latency of Nl at threshold for 10 msec was found to be 132.7 msec (S.D: 14.67). There was a significant delay (P.L: 0.0003) in Nl latency at threshold compared to that at 60 dBnHL, which was a consistent finding even for 100 msec duration.

Figure 2: LLR waveforms at different intensities for 10 msec stimulus.



a & b: Ipsilateral and contralateral LLR waveforms at 60 dBnHL for 10 msec stimulus.

c & d: Ipsilateral and contralateral LLR waveforms at threshold for 10 msec stimulus.

e & f: Ipsilateral and contralateral LLR waveforms below threshold for 10 msec stimulus.

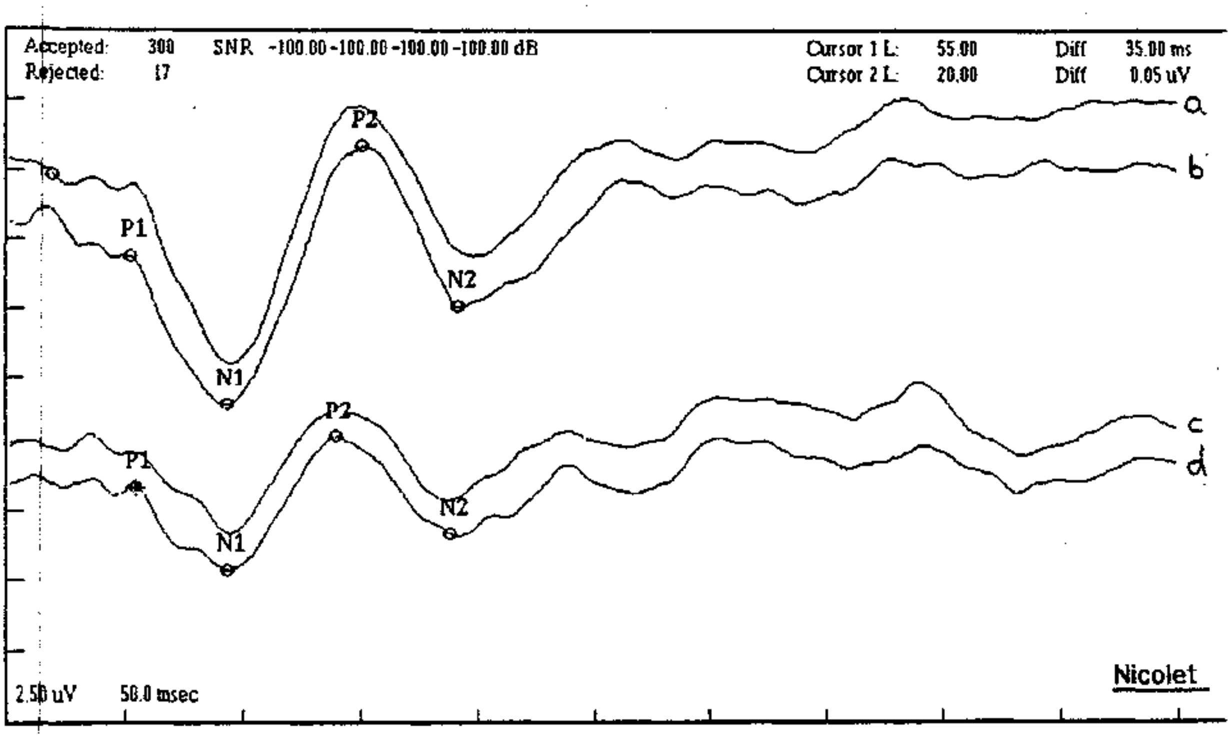
Table 5: Latency and amplitude of LLR at 60 dBnHL for 10 msec stimulus.

	P1 (msec)	Nl (msec)	P2 (msec)	N2 (msec)	N1-P2 uV)
Mean	63.75	103.4	162.4	225.35	2.9215
S.D	10.59	12.42	13.92	19.965	0.9785
N (number of subjects)	12	20	20	19	20

Comparison of results for 100 msec stimulus at 60 dBnHL (Table 4) with that of 10 msec (Table 5) shows that along with latency delay there was reduction in amplitude with decrease in duration. The waveforms in Figure 3 illustrate this effect. The increase in amplitude as duration was increased was found to be significant (P.L: 0.0001). This significant amplitude increase between 10 msec and 100 msec stimulus could be because of the difference in equivalent energy at the cochlea. Even though constant SPL (60 dBnHL) was presented to the ear, for 100 msec the equivalent energy at cochlea may be more due to temporal integration. The increase in amplitude with increase in equivalent energy is an expected finding. It has been reported in literature that the amplitude increased with increase in intensity upto 75 dB (Onishi and Davis, 1968; Spink, Johannsen and Pirsig, 1979; Spoor, Timmer and Odenthal, 1969). Onishi and Davis (1968) who have also found similar results for LLR recorded for stimulus of different duration attributed this relation between amplitude and duration to corresponding relation with loudness.

However, no significant difference in latency when the duration was varied was found in this study. This probably is due to the minimal change in latency of Nl or P2 components with intensity. It has been reported in literature that there is little change in latency of Nl or P2 components when the level is varied at supra-

Figure 3: LLR waveforms at 60 dBnHL for 100 msec and 10 msec stimulus.



a& b: Ipsilateral and contralateral LLR waveforms at 60 dBnHL for 100 msec stimulus.

c&d Ipsilateral and contralateral LLR waveforms at 60 dBnHL for 10 msec stimulus.

threshold (McCandless and Best, 1966; Rose and Ruhm, 1966; McCandless and Lentz, 1968; Onishi and Davis, 1968).

Thus, from the results, it is evident that LLR thresholds differ for 10 msec and 100 msec durations. 100 msec duration is found to be having better threshold suggesting that ear is integrating energy for a longer stimulus duration. An average threshold difference of 15 dBnHL was demonstrated by normal hearing subjects in this study for decade change in duration.

Chapter V

SUMMARY AND CONCLUSIONS

Stimulus duration is one of the important parameter influencing the detection of an auditory signal (Eddins and Peterson, 1999). The relation between stimulus duration and stimulus intensity in perception referred to as temporal integration (Pedersen and Elbberling, 1972a) has been generally studied using psychophysical methods (Sanders and Honig, 1967; Hattler and Northern, 1970; Florentine, Fasti and Buus,1988). Electrophysiological tools in studying such a phenomenon of audition, is a relatively new concept and very few investigations (Eddins and Peterson, 1999) in this direction have been conducted. This study attempted to explore the effects of decade change in stimulus duration on long latency responses.

The present study was hence conducted with the following aims:

1. To study the difference in LLR threshold as the stimulus duration was changed from 10 msec to 100 msec.
2. To study the latency, morphology, and amplitude variations for waveforms recorded at 60 dBnHL and threshold for both durations.

Twenty normal hearing subjects (10 males, 10 females) in the age range of 18-22 years were included in the study. LLR waveforms were recorded using Nicolet Bravo evoked potential system (version 1.5) with TDH-39 ear phones in MX-41/AR ear cushions and silver coated disc type electrodes. Stimulus used were 1 kHz tone bursts gated through Blackman window. Two stimulus durations, 10 msec and 100 msec, with rise-fall time of 4 msec were used.

For each subject LLR waveforms were recorded initially at 60 dBnHL and then the threshold was established for both 100 msec and 10 msec stimulus. LLR threshold was defined as the lowest level at which a repeatable Nl or P2 was identified. The waveforms thus recorded for two durations (100 msec and 10 msec) and two intensities (60 dBnHL and threshold) were analyzed.

From the results of the study following observations were made:

- LLR threshold for 100 msec stimulus was better than that for 10 msec for all subjects and the difference between the thresholds were found to be significant. An average difference of about 15 dBnHL was found for decade change in duration i.e., between 100 msec and 10 msec.

- As duration was decreased, morphology became poor, latency increased and amplitude reduced. The reduction in amplitude of N1-P2 was statistically significant but the change in latency was not statistically significant.

- For both the durations, as the intensity was decreased from 60 dBnHL to threshold, a statistically significant delay in Nl latency and reduction in amplitude was observed. In a majority of the subjects Nl was the only LLR component identifiable at threshold.

Implications of the study.

LLR can be used as an objective tool to evaluate temporal integration. The results of this study indicate that with decade change there is an improvement of 15 dBnHL in normal hearing subjects. Further studies need to be carried out to check if there is any deviation in the clinical population. This test may be of significance in differential diagnosis especially in identifying central auditory processing disorders if results similar to that observed in psychophysical studies (Jerger, Lovering and Wertz, 1972; Cranford, Stream, Rye and Slade, 1982; Thompson and Abel, 1992) can be replicated using electrophysiological measures.

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