MMN - AN OBJECTIVE CORRELATE OF DLI

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MAY 2000

CERTIFICATE

This is to certify that this Dissertation entitled : **MMN - AN OBJECTIVE CORRELATE OF DLI** is the bonafide work in part fulfilment for the degree of Master of Science (Speech and Hearing) of the student with Register No.M9809.

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CERTIFICATE

This is to certify that this Dissertation entitled : MMN - AN **OBJECTIVE CORRELATE OF DLI** has been prepared under my supervision and guidance.

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DECLARATION

This Dissertation entitled : **MMN - AN OBJECTIVE CORRELATE OF DLI** 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. M9809**

Venturing into the field of Audiology was
something I had never dreamt of !

To

Two people who unveiled
the mysteries of Audiology to me !

Chandan, for "leading me to it "

Vanaja ma'm, for "leading me through it"

अखंडमण्डलाकारम्
व्याप्तं येन चराचरम् ।
तत्पदं दर्शितं येन
तस्मै श्रीगुरवे नमः ।।

(Salutations to the Teacher,
who is omnipresent and source of knowledge and philosophies)

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The mediocre Teacher Tells;
The good teacher Explains;
The superior teacher demonstrates; but,
THE GREAT TEACHER INSPIRES
My Teacher, my Guide

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INTRODUCTION

The human ear is extremely sensitive to a wide range of stimulus intensities as well as frequencies. The frequency and intensity sensitivities interact affecting each other to a greater or a lesser degree. In addition to the above two factors, duration of a stimulus also affects the auditory sensitivity. Apart from being sensitive to a wide range of stimulus factors, the ear is also able to detect/discriminate small differences in a wide range of stimuli (i.e.) it has a remarkable differential sensitivity - the ability to detect very small differences between similar sounds. This ability applies to all the parameters : intensity, frequency and duration (Gelfand, 1981).

The smallest perceivable difference between two sounds is called the differential limen (DL) or the just noticeable difference (jnd). The change in intensity in dB which results in a just-bearly-noticeable loudness change is termed the intensity difference limen (DL) for loudness(SiIman and Silvennan,1991). Previous experiments done to calculate DLI have either used two different tones (Denes and Naunton, 1950; Hirsh, et al. 1954; Harris, 1963) or modulated tones (Reiz, 1978; Luscher and Zwislocki, 1949; Jerger, 1952). Psychophysical methods used to determine the DLI, however, involve a lot of subjective factors., Due to the subjective factors and due to differences in the methodologies used to obtain DLJ, DLI obtained by these procedures may not depict the auditory systems actual ability to discriminate between two similar stimuli. An objective method, if any, can be used to depict the auditory system's capability to discriminate between similar stimuli.

Recently, Mismatch Negativity (MMN), an event related potential has been shown to be present when 'deviant stimuli' occurring in a series of 'standard repetitive stimuli' which are just discriminable from the standard, but not when the deviants are not perceptibly different (Sams, et al. 1985). MMN also occurs when the subject discriminates between two stimuli at intensities similar to those used in normal speech. It has been reported that MMN can be recorded when the difference between the standard and deviant stimuli are as close to the DL and jnd, and occurs whether or not the subject is attending to the stimuli (Picton, 1995). It thus provides an automatic response that signifies the brain's detection of an acoustic change. It is thus, emerging as a objective electrophysiological measure of auditory discrimination.

MMN can be elicited by inducing changes in the basic acoustic features of the stimuli. Frequency discrimination/frequency limen as measured by MMN for a 1000 Hz pure tone has been reported to be around 5-10 Hz (Tiitinen, et al. 1994). This is larger than what has been reported by behavioural listening methods (i.e.) around 1-2 Hz for 1000 Hz (Wier et al. 1977). For complex sounds, the jnd of a frequency component depends on the spectral composition of that sound. However, there have been relatively fewer reports on the DL for intensity using MMN. The results on DL for frequency cannot be generalized to that of intensity. There is evidence that active discrimination performance correlates with the MMN amplitudes when using pure tones (Lang et al. 1990) and vowels (Aaltonen et al. 1995). There has however, been no systematic comparison study on the jnd of frequency or any other physical parameter of sound using both the AX-type active discrimination task and MMN. Therefore, this study attempts to compare DL for intensity in an AX procedure to that obtained by MMN.

Another aim of this study was to observe if stimulus intensity per se. had an effect on MMN and if that in turn would effect the DL for intensity obtained by MMN. Experiments using psychophysical methods to obtain DLJ report of differences in Weber fractions at different intensity levels of the stimuli (Jesteadt et al. 1977; Carlyon et al. 1984: Carlyon et al. 1986; Florentine et al. 1993). Even studies on MMN have shown that stimulus intensity has effects on the MMN peak amplitude (Schroger, 1994; Schroger, 1996; Sivaprasad and Iyengar, £099, Salo et al. 1999). Since DLJ obtained by psychophysical methods varies with intensity, variation in MMN can also be expected.

Thus the aims of the present study were :

(i) To compare the psychophysical data obtained by subjective (psychophysical) procedures to that obtained by MMN (physiological),

(ii) To study the effect of presentation (intensity) level of the stimulus on MMN i.e. latency, amplitude and duration and,

(iii) To compare latency, amplitude and duration of MMN for different deviances at the two presentation levels.

REVIEW OF LITERATURE

PSYCHOPHYSICAL LITERATURE ON INTENSITY DISCRIMINATION

Plack and Carlyon (1995) state that intensity discrimination refers to the ability of the auditory system to detect differences in the intensity of sounds, and a large number of experiments have attempted to measure this important aspect of the auditory function. Most of the experiments have used one of the two techniques, termed MODULATION DETECTION AND INCREMENT DETECTION. In modulation detection, listeners are required to detect the presence of slow amplitude modulation (AM), the threshold being taken as the smallest detectable depth of AM. In increment detection, listeners are required to detect a change in the intensity of a standard stimulus (the pedestal). The pedestal can be either continuously or gated with the increment. In the gated condition, the task is to usually discriminate a stimulus containing the increment from one with the pedestal alone (eg) "which of the two sounds louder". Thresholds measured using both the modulation detection and increment detection techniques have been interpreted as reflecting the accuracy with which intensity is coded in the auditory nerve. In the past, several different definitions have been employed for the "just noticeable difference for intensity (jnd)" or the Difference Limen Intensity (DLI). Plack and Carlyon (1995) report that the most common is DL and the Weber Fraction.

L=10 log(l+M/I)and
Weber fraction =M/I or 10 log (AI/I),
where I is the intensity of the pedestal,
and Al is the intensity of the smallest detectable
increment.

Green (1988), however, advocate the use of the pressure ratio expressed in dB (ie) 20 log (AP/P) for the studies of "profile analysis".

These units produce relative measures of the jnd, so that, in an increment detection task, if the intensity of increment is a constant proportion of the intensity of the pedestal, then 'L' the Weber fraction and the pressure ratio will also be constant (Plack and Carlyon, 1995). For wide band noise, the smallest detectable change in intensity I, is approximately proportional to the intensity of the stimulus, I (i .e.)AI/I is a constant This is WEBER'S LAW. This relationship holds good for intensities from about 20 dB above the absolute threshold to about 100 dB above absolute threshold (Miller, 1947). Within this range, a plot of 10 log (AI) against 10 log (I) will give a straight line with a slope of 1. In contrast to the results of wide band noise, for pure tones, the Weber fraction decreases slightly at high levels. This is referred to as NEAR MISS TO WEBER's LAW (McGill and Goldberg, 1968a) and is probably due to the spread of excitation along the basilar membrane associated with an increase in the intensity of the pure tone. Near absolute threshold, the Weber fraction increases dramatically, particularly at frequencies below 200 Hz (Ward and Davidson, 1993).

Inspite of all the recent studies, one of the earliest studies in the field of modern psychoacoustics which still provides the most comprehensive data concerning the discrimination of intensity is of Riesz (1928). However, there are many differences between Riesz's study and the studies carried out after 1930's. One important differenceis the stimulus configuration used to estimate difference limen. In Riesz's study, subjects were asked to detect beats. Operationally, this is equivalent to the detection of amplitude modulation (Rayleigh, 1894). In more recent studies, discrete signals (pulsed sinusoids) differing in intensity have been used and the subjects are asked to detect the more intense. There are data which suggest that procedures based on detection of modulation in an ongoing signal yield different results than those based on discrimination of discrete signals. Bilger et al. (1977) studied the effects of signal ensemble on intensity discrimination. DLI were calculated by amplitude modulation (AM) of a signal as well as by addition of an increment to the carrier at 1000 Hz. The DLI for the continuous carrier tended to be smaller than that of the pulsed carrier. Also, detection was more acute for AM signal than for fixed intensity difference, except at thresholds were the relation reversed itself. Inspite of the above fact, all the variability in the data cannot be attributed to differences in procedures and conditions. Even when comparison is restricted only to a few variables, the agreement is not very good as most of the studies do not contain sufficient information to estimate the reliability of the data. Because of this variability, no simple description *of* is possible since it depends both on frequency and intensity level of the signal as well as the procedure employed to obtain the DL. The factors afforementioned will be now dealt individually and discussed.

2.4

FREQUENCY EFFECTS

Most measures of intensity discrimination report of a monotonic decrease in intensity difference limens with increasing intensity/sensation level which is independent of the frequency. However, the exact nature of the relationship is dependent on the experimental task. A majority of studies on difference limen intensity have used pulsed sinusoids at frequencies below 4 kHz and investigators have filled different descriptive functions to their experimental data. Jesteadt et al. (1977) obtained intensity difference limens for pulsed sinusoids from 200 Hz upto 8 kHz for sensation levels ranging from 5-80 dB. They found that log (AI/I) decreased linearly as a function of SL, independent of the frequency. This result has also been reported by Dimmick and Olson (1941); Harris (1963); Schacknow and Raab (1973) and Penner et al. (1974). However, the study by Riesz (1928), using amplitude modulated signals shows that there is a frequency effect onil/I and that this is greatest at low frequencies as well as has sizeable effects at high frequencies.

Long and Cullen (1985) measured the intensity difference limens using both amplitude modulation at 2, 4, 6, 8 and 10 kHz and pulsed sinusoids at frequencies of 2,6 and 10 kHz for sensation levels of 15, 30, 45 and 60 dB and modulation rates of 2, 4 and 8 kHz. The difference limens for high frequencies calculated from amplitude modulation were found to change nonmonotonically as a function sensation level and the degree of departure from the monotonic relation increased with increase in the frequency. This relation is due to the gradual reduction of difference limen at the lowest sensation level with increasing frequencies. The same was observed for pulsed sinusoids too. Thus the data indicate that the monotonic relation between intensity difference limen and signal level associated with the "near miss" to Webers law seen for low frequencies does not hold good for high frequencies. It, thus appears that, this nonmonotonic relation between sensation level and intensity resolution is a general characteristic of stimulus processing at high frequencies. Florentine and Buus (1981) reviewed a number of studies which measured intensity discrimination at high frequencies and developed a model named "excitation pattern" model of intensity discrimination which predicted that difference limen functions at higher frequencies is very poor (i.e.) there is a close approximation to Webers law for high frequencies. This model is a multi band version and is in good qualitative as well quantitative agreement with the data, except at high frequencies. Florentine (1983) presented data consistent with the above said model. He studied intensity discrimination at 1 kHz and 14 kHz as a function of intensity, ranging from threshold to 10 dB below uncomfortable level. Results revealed that at 14 kHz, with an increase in level, there was a greater improvement in the intensity discrimination than at 1 kHz. However, DLs at 14 kHz were larger than DLs at 1 kHz at all intensities except at low SLs showing less deviation from Weber's law. All subjects though had variable discrimination thresholds, showed an improvement with increasing level at 1 kHz. This is due to spread of excitation over a wide range of frequencies for 1 kHz than for 14 kHz as suggested by Zwicker (1958). In order to verify this experimentally, Florentine (1983) in the same experiment measured intensity discrimination for a 90 dB SPL tone at

1 kHz with and without noise. Eight high pass noises with cut off frequencies between 6-19 kHz were used. It was found that simply changing the cut off frequency of the masking noise from 6 to 19 kHz decreased the DL at 1 kHz by a factor between 1.5 - 2.00, emphasizing the fact that audibility at high frequencies is important for intensity discrimination at 1 kHz for high levels. Thus the results of the these experiments are consistent with the excitation pattern model of intensity discrimination and highlight the effects of high frequency on intensity discrimination.

Carlyon and Moore (1984), have reported that intensity discrimination of 6.5 kHz pulsed pure tones was not constant or monotonic with increasing the sensational level. 500, 4000 and 6000 Hz, pure tones (pulsed) were used at 22, 55 and 85 dB SPL. It was found that at lower frequency, the intensity DL remains almost constant over a wide range of levels and DL is affected only slightly by adding band stop noise centered at the signal frequency. For high frequency tones, however, intensity discrimination deteriorates at intermediate sound levels (55-70 dB). This deterioration is more marked for short duration tones presented in band stop noise centered at the signal frequency. The large effect of band stop noise suggests that at high frequencies at short durations, subjects use information from neurons with critical frequencies (CF) remote from the signal frequency. Band stop noise prevents this off frequency listening and causes an increase in the DL. Thus Carylon and Moore (1984) propose that intensity discrimination at lower frequencies across levels is maintained by a combination of "firing rate" and "phase locking events". One or both these types of information is available even in the presence of band stop noise. At high frequencies, phase locking information is absent and at high frequencies, a mid level deterioration may be due to firing rates being impoverished and this could be because of a processor at a "later stage" with a high level of internal noise. They also reported that detailed study of the data of Jesteadt et al. (1977) and Harris (1963) also revealed a similar nonmonotic change in intensity discrimination with sensation level for higher frequencies. From examination of Florentine's (1983) data, it can be seen that at 14 kHz the difference limen intensity for lowest sensation levels is lower than predicted and those near 40 dB SL are somewhat larger than what can be expected. Thus, intensity discrimination appears to be nonmonotonic as a function of levels at high frequencies (Carlyon and Moore, 1984). Similar results have been reported by Florentine et al. (19$7) who studied level discrimination for frequencies from 0.25 kHz to 16 kHz. Schroder et al. (1994) reported of results which are consistent with Jesteadt et al's (1977) study only at moderate intensities with increase in frequency. With increase in level at high frequencies, the Weber fraction tended to decrease slightly. Further analysis to test the effect of frequency revealed significant differences in the slopes of the Weber function with increase in frequency (i.e.) the slopes became progressively steeper at higher frequencies and this result is consistent with the findings of Florentine and Buus (1981) and Florentine et al. (1987).

Thus most of the studies show that Weber fractions for pulsed tonal stimuli are independent of frequency for frequencies from 250 Hz at 14 kHz, but,at higher frequencies, there is a small maximum at medium pedestal levels, suggesting a nonmonotic relation between level, frequency and intensity discrimination.

INTENSITY EFFECTS

Intensity discrimination as a function of *level* have been measured in many studies, but most of the earlier done studies do not report of data for a wide range of levels. The most well known effect of intensity discrimination as a function of level is the "near miss to Weber's law (i.e.) for pure tones and other low pass stimuli, the Weber fraction (Al/I) decreases at higher intensities of the standard- This has been demonstrated by a number of studies which will be dealt in detail in the following sections. Other than the"near miss", the effect of level also varies as a function of frequency and hence affects the differential limen for intensity measured at different frequencies. Even these need to be considered while discussing the effects of level on intensity discrimination.

Jesteadt et al. (1977) measured the Weber fraction ($\Delta I/I$) as a function of level ranging from 5-80 dB SLs. The data indicated that $\Delta I/I$ decreased linearly as a function of level (i.e.) in accordance with the "near miss" to Weber's law. These results are consistent with the study of Harris (1963), however, the only difference being that the slopes in study by Harris (1963) were much shallower than those found by Jesteadt etal. (1977).

The results of investigation by Jesteadt et al. (1977) differ from several previous studies in that the function describing log $(\Delta I / I)$ as a function of SL holds at low sensation *levels* as well as high levels. Campbell and Lasky (1967) and McGill and Goldberg (1968a, 1968b) found the function to be not only nonlinear, but nonmonotonic at low SL's. The authors however did not find any evidence in their data to show that deviations from Weber's law at low levels is different from what it is at higher levels. The difference between the present data and earlier data could be due to the result of a low level background noise and hence higher signal levels when specified in SPL. Earlier Rabinowitz et al. (1976) combined data from 15 studies of intensity discrimination at 1 kHz for a range of SL's and concluded that Weber's law was valid only from 10 to 40 dB SL, with poor resolution below 10 dB SL and steady improvement above 40 dB SL. Some of the studies, however, report of a slight departure from the monotonic relation between intensity discrimination and sensation levels for signals between 10 and 40 dB SL (Campbell and Lasky, 1967; McGill and Goldberg, 1968 a; Rabinowitz, 1970). However Rabinowitz et al. (1976) concluded that such a departure is very slight when averaged over studies. Florentine and Buus (1981) also reviewed a number of studies which measured intensity difference limen at different levels and frequencies and concluded that there is a four to five fold decrease in the DL obtained as the level increases from 10 to 90 dB SL. The single-band version by Zwicker (1956, 1970) for intensity discrimination, however, cannot explain this increase in DL with increase in level. So Florentine and Buus (1981) gave a multi band version for explaining this phenomenon and named it "excitation pattern model" of intensity discrimination. Thus, most of the experiments relating to the effect of level on DL indicate that there is an increase in DL with increase in the level.

As discussed earlier, the effect of level on DL varies as a function of the frequency also Florentine (1983) conducted a study wherein DL was measured at 14 kHz and 1 kHz for test levels that encompassed a range from threshold to roughly 10 dB below discomfort level. Results show that intensity discrimination improves less with increasing level at 14 kHz than at 1 kHz. DLs at 14 kHz are larger at all levels except at lowest sensation levels. All subjects showed improved discrimination with increasing level at 1 kHz, but little improvement with increasing level at 14 kHz. Close examination of this data reveals that at 14 kHz, difference limens for lowest sensation levels are smaller than predicted and those at 40 dB SL, somewhat larger than predicted. Thus intensity discrimination appears to be somewhat non-monotonic as a function of stimulus intensity even at very high frequencies. Carlyon and Moore (1984) also found similar results for 6.5 kHz tone with increasing sensation level. Florentine et al. (1987) studied level discrimination as a function of level for tones from 0.25 to 16 kHz and found that DLs at all frequencies but for the highest frequencies, they are generally smaller at high levels than at low levels. It was also found that DL at equal SPLs are largely independent of frequency upto 4 kHz, but increase with frequency above 4 kHz. At 8 and 10 kHz, the DLs are clearly nonmonotonic functions of levels showing consistent deterioration in the mid level DLs relative to the low and high level DLs. Thus not only does DL show a change as a function of level, but also due to an interaction of frequency and level.

Florentine (1983) reported that intensity discrimination at high levels correlates with high frequency thresholds. DL for 1 kHz tone at 80 dB SPL was plotted as a function of high frequency cut off for individuals. A high frequency cut off was defined as the minimum frequency at which the threshold exceeded 80 dB SPL. A linear regression analysis showed a significant negative correlation between DL at 80 dB and high frequency hearing. Results of this study are consistent with the multi band version of the excitation pattern model for intensity discrimination.

DURATION EFFECTS

Henning (1970) reported that, up to a certain duration, the energy of the smallest detectable increment on gated pure tone pedestals is a constant. Hence, the Weber fraction decreased by 3 dB with every doubling of duration within this limit. Beyond this critical duration, the Weber fraction was constant. The value of the critical duration decreased with increasing pedestal frequency, from 100 ms at 250 Hz to 10 ms at 4 kHz. Florentine (1986) measured difference limens for level ([L=20 log (p+ΔP)/p] as a function of duration for tones at 250, 500 and 8000 Hz. Stimulus duration ranged from 2 ms to 2 sec. and stimulus power was held constant. At each frequency three levels were tested (ie.) 85, 65 and approximately 40 dB SPL. Results indicated that ALs decreased as duration increased, up to at least 2 sec. exceptat 250 Hz. At 250 Hz, AL stopped decreasing at durations between 0.5 and 1 sec. The slope of the logarithmic plot of ΔL versus duration was found to be steeper at high levels than at low levels (The average slope was (-0.28)]. Since the average slope is lesser than/shallower than-.05 slope predicted for an optimum detector, it may be that fast adaptation of auditory nerve activity and/or memory effects interfere with level discrimination of long-duration tones. She, thus reported of critical durations of 500 ms at 250 Hz and over 2 sees, at 8 kHz. The discrepancy between this study and the one by Henning (1970) could be because of the smaller range of stimulus duration used by Henning (1970).

The rate of decrease of the Weber function with duration seems to be inversely related to the bandwidth of the pedestal, so that intensity discrimination measured with wide band noise pedestals shows only a slight improvement with duration (Raab and Goldberg, 1975).

Another factor affecting the relationship between Weber fractions and duration may be the intensity of the pedestal. Carlyon and Moore (1984) reported that the mid level deterioration in intensity discrimination at high frequencies was more marked for short than for long duration stimuli. They used tones of 5,10,20,30,40,50,60 and 70 msec duration at 55 dB SPL for 500 Hz, 4000 Hz and 6500 Hz frequencies $10 \log (\Delta I/I)$ was estimated. They also used a band stop noise which was either gated on and off with the signal or was absent. Results indicated that in conditions without band stop noise, performance worsened slightly with decreasing duration. This effect was slightly greater at lower signal frequencies. In presence of band stop noise, performance gets steadily worse with decreasing duration for 4000 and 6500 Hz tones. There, was a much smaller effect of duration on the thresholds for 500 Hz tones. It could be that the reduction in information conveyed by VIII nerve fibers produced by shortening duration is not sufficient to impair performance markedly at low frequencies. This could reflect the use of phase-locking at low frequencies. The small effect of duration, even at high frequencies when band stop noise was absent may reflect the integration of information across different parts of the excitation patterns evoked by the signals.

Florentine and Buus (1991) studied the sensitivity (d^f) to level differences as a function of duration. They studied tonal stimuli ranging from 0.25 to 14 kHz and broad band noise. The levels used ranged from 30 to 90 dB SPL. For each stimulus, the level difference ΔL = (ΔL=20 log [p 4AP/P]) and the stimulus power were kept constant while duration varied from 2 to 2000 ms. Results showed that the sensitivity d' increased as a power function of duration upto a critical duration. The critical duration reported are in good agreement with Florentine's (1986) data.

MODELS OF INTENSITY CODING

Plack and Carlyon (1995) suggested that by studying intensity coding, we study/determine how the ear tells the brain how intense a particular sound is, or, more specifically, how the physical intensity of a sound is represented in terms of the activity, or pattern of activity of nerve fibres in the auditory system. Intensity coding, is, therefore, inherently related to intensity discrimination (eg) the ability to "hear" two sounds of 120 dB and 130 dB, does not imply that these intensities are represented differently in the auditory system; they may produce identical percepts. If a listener, however, can detect a difference between the two sounds, that difference must be represented at all stages in the auditory pathway between the cochlea and the decision process,

The fidelity of the coding mechanism will determine the smallest difference that can be detected. Intensity discrimination experiments are therefore the primary psychophysical tools for testing models of intensity coding.

A successful model of intensity coding has to take account of the frequency selectivity of the cochlea, so that intensity is encoded independently for different frequency channels, eventhough this information may be combined at some later stage. The firing rates of fibres in the auditory nerve are generally monotonically related to physical intensity. A simplistic hypothesis, therefore, is that die intensity in any given frequency region is coded purely by the firing rate of fibres tuned to that frequency region; the higher the intensity, the higher the firing rate (Plack and Carlyon (1995). Although this account may turn out to be accurate in some circumstances, there are several complications will be discussed later. One of the most important one is that of the "Dynamic Range".

Viemeister and Bacon (1988) reported of the auditory systems capability to detect differences in intensity of sounds over a wide dynamic range; as much as 120 dB in normal hearing listeners. The majority of auditory nerve fibres, those with a relatively high spontaneous rate (SR), have low thresholds but relatively small dynamic range, with most showing saturation in their firing rate above an intensity of around

60 dB SPL when stimulated by a tone at their characteristic frequency (CF) (Palmer and Evans, 1979) (i.e) increases in stimulus intensity beyond this point will not result in a change in the firing rate of the majority of auditory nerve fibres. Also, the fact that Weber's law continues to hold even at high stimulus intensities has lead researchers to examine ways in which stimulus intensities may be coded other than by the firing rate of the nerve fibres tuned to the pedestal frequency. This lead to a number of models which have tried to explain the intensity coding. Plack and Carl yon (1995) classify these models into two categories:

a) PERIPHERAL MODELS OF INTENSITY CODING
b) CENTRAL MODELS OF INTENSITY CODING

a) **PERIPHERAL INTENSITY CODING**

Models which deal with explaining the coding of intensity at the periphery, mainly at the level of the cochlea, are known as peripheral models of intensity coding.

i) *CODING BY SPREAD OF EXCITATION*

Siebert (1965) reported that one possible explanation of the apparent problem of the dynamic range is that, at least for narrow band pedestals, information regarding the intensity of a sound is available from nerve fibres tuned to frequencies above and below the pedestal frequency. Although most fibres tuned to the pedestal frequency will be saturated by an intense pedestal, fibres with CFs remote from the pedestal frequency will receive excitation and may not be saturated. Zwicker (1956). suggested that this "off-frequency" fibres are responsible for coding intensity at high levels. Zwicker (1956) and later Maiwald (1967) had proposed an "excitation pattern model" for intensity discrimination and that was the "single band version". They assumed that the performance is determined by the critical band in which the excitation grows most rapidly with increasing level of the stimulus. This model was put forth to account for intensity discrimination of amplitude modulated tones. Later Zwicker (1956) and Maiwald (1967) put forth a multi band version of the same model. However, most modern experiments have measured intensity discrimination of pulsed tones. Therefore it was evaluated again to determine if the single band version of the excitation pattern model could account for the data obtained from pulsed sounds. Florentine and Buus(1981) proposed a multiband version and showed that the data on pulsed tones generally fit well in this version. Moreover data on effects of masking on intensity discrimination of tones clearly suggest that the spread of excitation is towards the higher as well as lower frequencies and this affects intensity discrimination (Viemeister, 1972; Moore and Raab, 1974; Hellman, 1978). The maskers produce a slight increase in the Weber function at high intensities. Therefore, to be consistent with these results, the excitation pattern model for intensity discrimination must use information in critical bands across frequencies (i.e.) the entire frequency. This model highlights on the fact that information is optimally combined from all the regions of the excitation pattern. Although, both the versions of the excitation pattern model predict qualitatively the near miss and its removal by masking with notched noise, the single band version is not in good agreement with the intensity resolution data for pulsed tones. Thus, results from masking experiments have been taken as evidence that although spread of excitation may aid intensity discrimination at high intensities, producing the near miss, the auditory system can code intensity over a large dynamic range on the basis of information from a small range of CFs.

ii) ***CODING BY NEURAL SYNCHRONY***

Carlyon and Moore (1984) suggested that, in some circumstances, intensity might be coded by the pattern of phase locking in auditory nerve fibres. This might be used at frequencies below 4-5 kHz where synchronization of a fibre's discharge to a particular phase of the input waveform. Increasing the intensity of a pure tone in the presence of a noise can produce an increase in the synchronization to the fine structure of the pure tone, away from the fine structure of the noise, even though the overall firing rate of the fibre does not change (ie) eventhough the fibre is saturated (Javel, 1981). In particular, in experiments which have used notched noise intensity differences at high intensities could have been detected as a virtue of an increase in the degree of synchrony in the firing of a neuron tuned to the pedestal frequency. Carlyon and Moore (1984) tested this hypothesis in an experiment and found that "phase locking/neural synchrony" does play a role in intensity coding, but is not solely responsible for the large dynamic range observed.

iii) *MODELS BASED ON RATE-INTENSITY FUNCTIONS*

It is known that the dynamic range in a single frequency channel is probably much greater than that observed for fibres with high spontaneous firing rates (SR). The dynamic range of hearing must depend, therefore depend on the minority of auditory fibres with low spontaneous rate of firing. Sachs and Abbs (1974) have shown that these fibres have higher thresholds (than the high SR fibres) and have larger dynamic ranges, many of which extend up to very high intensities. A hypothesis put forth to explain the dynamic range of hearing is that the high SR fibres are responsible for conveying intensity information at low stimulus intensities and the low SR fibres are responsible for coding at higher intensities. This is referred to as "dual population model" of intensity coding. The main drawback of this model is that it has difficulty explaining why Weber fraction is roughly constant for a wide range of stimulus intensities. Numerous attempts have been made to model intensity discrimination using the rate intensity functions of the auditory nerve fibres (Winslow and Sachs. 1988; Young and Barta, 1986; Delgutte, 1987; Viemeister, 1988). These models highlight that sufficient information is available in the firing rates of auditory nerve fibres to encode intensity over a wide range of intensities.

Thus, all the peripheral models of intensity discrimination highlight the importance of the nerve fibres and changes in their firing rate which signal changes in intensity. Now, we will consider more generally the factors that limit our ability to detect changes in the intensity of sounds, including processes which are central to auditory nerve.

PERIPHERAL AND CENTRAL LIMITATIONS

The richness of the representation in the auditory nerve and the failure of models of intensity coding based on properties of the auditory nerve fibres to account for Weber's law, implies that some process central to the auditory nerve may not be making the optimal use of the neural information (Carlyon and Moore, 1984). Presumably, this "central limitation" determines discrimination performance in most circumstances and prevents human performance from being better at low and medium intensities than at high intensities. This central limitation has been hypothesized as a constant internal "noise" or variability, added to the decision process. These central processes are related to functions of memory (i.e.) how intensity is coded in memory and how memory limitations affect the performance on discrimination tasks.

The importance of peripheral information in intensity discrimination have already been highlighted by experiments that have reduced or degraded the information in the physical stimulus available to the auditory system and they have provided valuable clues as to the nature of peripheral limitations to intensity coding.

b) **CENTRAL INTENSITY CODING**

As already said earlier, the most important central process in intensity discrimination is "memory".

As is known that most intensity discrimination experiments employ a two-alternative task in which the listener is required to choose which of the two observation intervals, separated by an inter stimulus interval (ISI) contains the intense stimulus. This task can be performed in two different ways. First, the listener can directly compare the intensities of the stimuli in two observation intervals and this requires that the listener store a representation of the intensity of the first stimulus in short term memory. Second, if the pedestal or standard, has the same intensity across a number of trials, then the listener may form a long term representation of this intensity that can be used to perform the discrimination task. The absence of a significant ISI effect in intensity discrimination tasks employing fixed standard supports the idea that listeners use long term memory. A short term store would decay over time, producing a large effect of ISI. The long-term memory we can also be removed by randomly varying or roving, the intensity of the standard between two stimuli with in each trial when this is done, performance consistently worsens with increasing the ISI (Berlin and Durlacn, 1973; Green, et al. 1983). For a 100 ms, 1 kHz 3 sinusoid, the Weber fraction increases from about -2 dB to 5 dB as ISI increases from 250 ms to 8 secs, his reflects decay of the short term memory trace.

Durlach and Braida (1969) have described a model of intensity coding that includes two different modes of memory operating: "the trace mode" and "the context-coding mode". In the "trace mode", the direct sensations produced by the stimuli are stored. These sensations have a tendency to decay over time, leading to an increase in me "memory noise" and accounting for the effects of ISI.

"Context-coding" on the other hand involves a process wherein intensity is coded relative to a reference intensity or a relative internal "perceptual anchors" (eg) the absolute threshold or the discomfort threshold. The accuracy of the coding is supposedly dependent upon the distance on the sensation axis between the sensation of the target stimulus and the sensation of the anchor. This hypothesis accounts qualitatively, at least for the several of the phenomenon observed in the discrimination experiments (eg) elevation of Weber fraction at medium intensities only; tone bursts at high frequencies in notched noise or tone bursts in non-stimultaneous masking. The central intensity coding proposed to account for the intensity discrimination using psychophysical procedures can also be linked to the hypothesis proposed for the generation of MMN. The "trace mode" of intensity coding as proposed by Durlach and Braida (1969) is very similar to the 'memory trace hypothesis' put forth by Naatanen (1990) which states that our brain encodes physical features of the acoustic input into short lived neural traces (i.e. sensory memory), establishes representation of repetitive features in the acoustic input as a neural model (norm) and compares each input with this norm. If a difference is detected by this memory comparison process, MMN is elicited. These traces also fade away with time and are said to last for about 10 secs (Sams et al. 1993). Thus with increase in the interstimulus interval beyond 10 sec, MMN would no longer be elicited.

Thus, there seems to be similarity in the models proposed to account for intensity discrimination and that put forth for MMN generation. From the above, it is obvious that the auditory system needs to code intensity in a relative way because the auditory stimuli are defined by the relative intensity of features either simultaneously present or proximal in time. Consistent with the relationship of relative intensity to stimuli identification, the context code is often regarded as the 'categorical" type of memory trace, so that, for example the discrimination of spectral shape of the stimulus as "bumped" or "flat" helps the listener to categorize and use these as basis for discrimination. However, absolute intensity does not affect the identification of auditory stimuli in most circumstances (Plack and Carlyon, 1995). It, therefore seems that the auditory system should be good at "short-range" comparisons of intensity rather than comparisons over several hundred milli seconds. Much of the discussion is still speculative and these hypothesis are open to experimental investigation.

Thus the peripheral and the central models of intensity coding provide a great deal of information as to how intensity is coded in the auditory systems and the mechanisms that underlie an auditory discrimination task.

PHYSIOLOGICAL REVIEW ON CHANGE DETECTION

Auditory discrimination, apart from being studied/measured by psychophysical methods, has also been studied using electrophysiological techniques. The Event-related brain potentials (ERPs) in response to auditory stimuli have proved useful in studying the brain mechanisms underlying human auditory stimulus discrimination (Donchin et al. 1978; Ritter et al. 1979; Curry et al. 1983; Fitzgerald and

Picton, 1983). In the discrimination studies carried out by electrophysiological measures, "oddball" paradigm is used wherein the subject is instructed to discriminate the infrequent and unpredictable deviant stimuli presented among frequent "standard" stimuli. In comparison to the latter, the detected deviant stimuli elicits a negative deflection (N200 or N2) with a latency of approximately 200 msec, followed by a positive P300 deflection (Donchin, et al. 1978). The latencies for both N200 and P300 correlate with the difficulty of the discrimination task as well as the reaction time (Ritter, et al. 1972; 1979; Ford et al. 1976). However, since the motor activity in the cortex related to the outcome of stimulus discrimination is often prior to P300, N200 seems to be more intimately related to the discrimination process than P300 (Donchin et al. 1978).

Naatanen et al. (1982) suggested that N200 elicited by the deviant stimuli in oddball paradigm is composed of two component speaking within the same time window. They were labelled the 'mismatch negativity' (MMN) and N2b by Naatanen et al. (1978,1980) and Naatanen et al. (1982), respectively. The MMN is independent of significance of the stimulus and direction of attention (Naatanen et al. 1978, 1980). Subsequent research has established that MMN is an auditory evoked response that is associated with automatic detection of changes in the acoustic flow of stimulus and is elicited by the deviants in the 'oddball paradigm' even when the subject is engaged in visual task (Naatanen et al. 1982).

Changes in repetitive physical features of the acoustic input elicit the mismatch negativity. This is assumed to occur when the deviant stimulus is automatically compared with the neural trace created by the standard stimuli and the difference is detected. The MMN can be elicited to differences in frequency (Sams et al. 1985), intensity (Naatanen et al. 1989), duration (Naatanen et al. 1989), direction of the sound (Paavilainen et al. 1989) and to phonetic changes. The MMN is symmetrically generated in the primary auditory cortices or close to them (Hari et al. 1984). A third MMN generator is apparently said to be located in the right hemisphere (Giard et al. 1990). Furthermore, since the MMN is also elicited when the subjects do not actively listen to the auditory stimuli, it is suited to studying attention independent processing involved in auditory sensory memory and change detection.

Auditory frequency discrimination using event-related potential has been studied by Sams et al. (1985). They used stimulus blocks which standard had frequency of 1000 Hz and deviants of 1002 Hz, 1004 Hz, 1008 Hz, 1016 Hz or 1032 Hz, one deviant type in each block. The interstimulus interval was 1 sec. and the subject were instructed either to ignore the deviant or to press a response key to them (discrimination condition). The intensity of the stimuli were 80 dB SPL. Results indicated that in the ignore condition, the MMN appeared with a peak latency of about 170 msec, only for deviants exceeding the discrimination threshold (i.e.) only by 1016 Hz and 1032 Hz. However, though MMN was elicited at the threshold (i.e.) 1008 Hz, it tended to be of smaller amplitude. In the discrimination condition, in addition to MMN, another negative component, N2b was also elicited by the deviants. This component had a somewhat longer latency than the MMN and its midline distribution was posterior to the MMN. Thus these results are in line with the hypothesis that MMN component reflects the activation of cerebral mechanisms of passive discrimination.

More recently Salo et al. (1999) have studied the intensity dependence of automatic frequency change detection using MMN. The stimuli used were a 1000 Hz standard and a 1141 Hz deviant tone at 40, 50, 60, 70 and 80 dB HL. They found that the MMN mean amplitudes increased as the intensity of the stimulus was increased. Also an effect of intensity was observed on MMN onset latencies. The latencies were shorted at 60 and 70 dB HL. However with further increase (i.e.) 80 dB, the onset latency increased again. The shortest latencies at 60 and 70 dB HL may suggest that the frequency discrimination is fastest at these stimulation levels. These results are in contradiction to an earlier study by Schroger (1996) who reported of MMNs being no change in the MMN amplitude at 70 dB SPL compared to 55 dB SPL in a frequency change paradigm. Earlier Schroger (1994) had reported that supraliminal stimulus intensity has no effect on the MMN. Thus intensity of the stimulus does seem to have an effect on the automatic detection of frequency changes of the stimuli. However, the results of the studies done in this aspect are equivocal.

All these mentioned studies have been performed using on frequency discrimination paradigm. Schroger (1996) however, studied automatic intensity discrimination and the effects of intensity and interstimulus interval (ISI) on intensity discrimination task. The intensities used were 55 dB and 70 dB SPL and the ISIs were 350 msecs and 950 msec. Results indicated that with increase in the intensity, the amplitude of MMN increased, a finding in accordance with even psychophysical studies. Recently Sivaprasad and Iyengar (2000) have also reported of an increase in the absolute MMN amplitude with increase in the intensity level of the stimulus.

The dependence of MMN on absolute intensity level is consistent with both, the memory-trace hypothesis and the new-afferent element hypothesis. As regarding to the ISI, the MMNs are larger with longer ISI compared to the shorter ISI. Thus, the observation that the frequency MMN did not depend on intensity and ISI, whereas the intensity-MMN was modulated by these experimental variables, reveals that the automatic change detection is not performed by a unitary system but by functionally different subsystems. These functional differences could be probably due to differences in the underlying processes coding the critical stimulus information in to sensory memory traces. Moreover, it is also known that the attentive change detection system makes use of the information computed by the automatic change detection (Schroger, 1996).

Thus, as seen in most of the above reviewed psychophysical and physiological studies to establish a correlation between DLI (established) by subjective method/s and that obtained by the objective method/s has not been attempted widely. Thus, in the present study, an attempt has been made to observe if a correlation exists between DLI obtained subjectively and objectively. Also, the effects of stimulus presentation on MMN and its effect on DLI traced using MMN has also been studied to see if the results mirror what is reported in psychophysical studies. If the above two attempts do show correspondence to results of psychophysical studies and if the DLI traced using MMN is smaller than that obtained through a subjective method, then MMN can be considered as a more objective method to establish DLI and can be considered as an objective correlate of DLI.

METHODOLOGY

The present study was undertaken to

a) Compare the psychophysical and physiological Differential Limen for Intensity (DLI)

b) Investigate the effects of different intensities on Mismatch Negativity (MMN)

Subjects

20 subjects (10 males and 10 females) between 18-24 years of age$_A$included in the study.

Subject Selection Criteria

1. Subjects had normal hearing thresholds i.e. < 15 dB HL.
2. None of the subjects had any past or present history of otological/ neurological/psychological problems.
3. The subjects were able to relax in the presence of electrodes placed for the duration of testing.

Instrumentation

Biologic-evoked Potential (Navigator) System (EP-317 software) and TDH-39 earphones with MXH-41/AR were used.

Test Procedure

a) Psychophysical DLI

(i) *Estimation of threshold*

- Biologic evoked potential system was used to estimate thresholds behaviourally for 1000 Hz alternating tone bursts.

(ii) ***Differential limen***

- The **DLI** was obtained for 1000 Hz using the method putfoith by Jerger (1953) i.e. at 10 dB SL and 40 dB SL (Ref/Threshold in nHL) using Biologic Evoked Potential (Navigator) System.
- 'Yes-No' procedure was used to calculate the differential limen.
- The subjects were instructed to indicate for the modulation of intensity in the tone under 2 conditions viz.

(i) only when they were 100% sure that the tones were different,

(ii) When they were even little sure that the tones were different.

(b) Physiological DLI (MMN recording)

(i) *Subject set-up.*

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

(ii) ***Instructions to the subjects***

The subjects were instructed not to pay any attention to the auditory stimuli.

(iii) *Electrode placement*

Cz and Pz were considered as positive electrode sites; Fpz as common whereas Ml and M2 as negative sites.

Site	Electrode Box Connection
Forehead	Common
Vertex	Channel 1; input 1
Left mastoid	Channel 1; input 2
Parietal	Channel 2; input 1
Right mastoid	Channel 2; input 2

Silver Chloride disc electrodes were fixed at the above said sites after a thorough skin surface cleaning with surgical spirit and a skin preparing solution and later fixed with standard EEG paste suitably secured in place with surgical tape.

(iv) *Measuring impedance*

Impedance with reference to the common electrode was measured for both the channels. The electrode impedance values were less than 5 kOhms and the interelectrode impedance difference was less than 3 kOhms, the electrode sites were cleaned again. The negative electrodes (Ml and M2) were linked together by means of a jumper.

(v) *Test protocol*

MMN was recorded using the following protocol:

- (i) Stimulus type : Alternating tone burst
- (ii) Frequency: Frequent stimulus : 1000 Hz,Infrequent stimulus 1000 Hz
- (iii) Intensity : Frequent stimulus =10 dB SL and 40 dBSL (Reference:thresholds for tone burst in nHL).
- (iv) Deviance:
  Psychophysical DLJ was kept as the initial deviance. This deviance was then reduced in 1 dB step till no MMN was elicited.
- (v) Repetition rate - 1.1/sec
- (vi) Rise time - 10 msec
- (vii) Plateau - 30 msec
- (viii) Fall time - 10 msec
- (ix) Gain - 50,000
- (x) Maximum stimuli- 500
- (xi) Band pass filter - 0.1 Hz to 300 Hz
- (xii) Ratio of the frequency : infrequent = 5:1
- (xiii) Transducer - Headphones

Analysis of MMN

-> The measures used for analysis were

a) Latency (b) Amplitude (c) Duration

The physiological DLI was considered as that least difference wherein a MMN was recorded. The following were the criteria used for MMN identification:

a) A trough in the latency range of 50-300 msec.

b) Should be a negative potential of amplitude more than - 0.3uV

c) Should occur either in the N1P2 complex or P2N2 complex.

d) The negative peak should be followed by a positive peak.

RESULTS AND DISCUSSION

The aims of the present study were :

a) To compare the psychophysical difference limen obtained by subjective procedures to that obtained physiologically using MMN.

b) To study the effect of presentation (intensity) level of the stimulus on MMN i.e. its effects on the latency, amplitude and duration of MMN, and

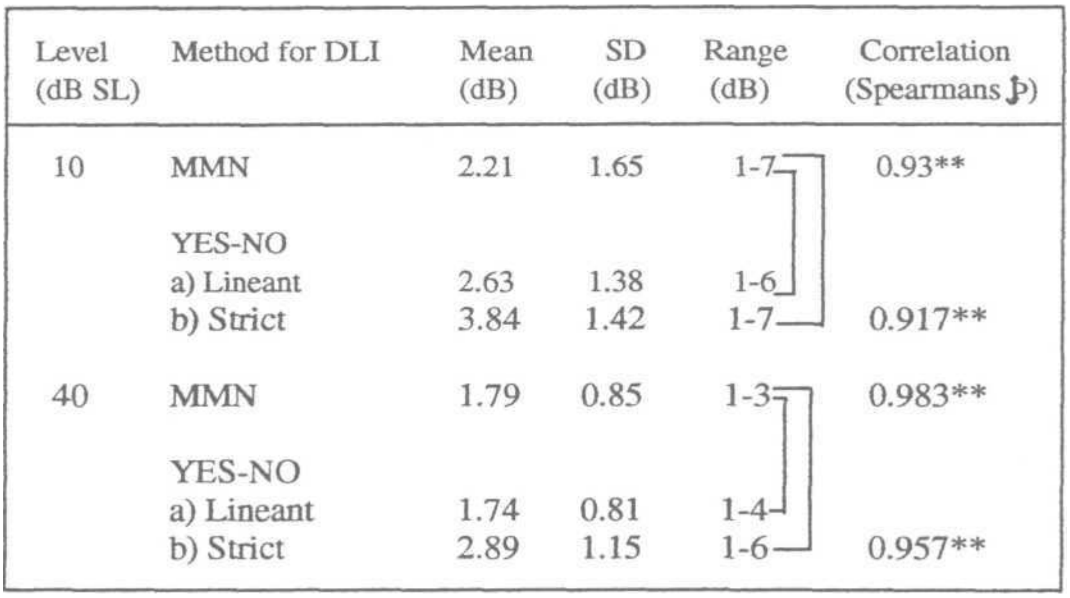
c) To compare the latency, amplitude and duration of MMN at different deviances at both the presentation levels.

The DLI obtained psychophysically and physiologically were in dB nHL. The criteria for MMN identification as mentioned in the methodology were used and the lowest deviance at which MMN could be identified was taken as the DLI i.e. physiological DLI. One data was deleted from analysis as no MMN was noticed for any deviance at both the presentation levels.

a) *Psychophysical DLI vs. Physiological DLI*

Table-1 represents the mean, standard deviation and range for the DLI obtained psychophysically, using both the criteria and physiological DLI using MMN. As can be seen, the mean values for psychophysical DLI's were greater than the physiological **DLI** at both the presentation levels. Also DLI obtained using both psychophysical and physiological procedures at higher presentation level was lesser than that at low presentation level. The results also revealed that the psychophysical DLI obtained using a strict criterion was higher than that obtained using a lineant criterion at both presentation levels.

Table-1 : Means, standard deviations and range of DLI s obtained using MMN and that using subjective methods.



Level (dB SL)	Method for DLI	Mean (dB)	SD (dB)	Range (dB)	Correlation (Spearmans ρ)
10	MMN	2.21	1.65	1-7	0.93**
	YES-NO				
	a) Lineant	2.63	1.38	1-6	
	b) Strict	3.84	1.42	1-7	0.917**
40	MMN	1.79	0.85	1-3	0.983**
	YES-NO				
	a) Lineant	1.74	0.81	1-4	
	b) Strict	2.89	1.15	1-6	0.957**

** Significant at 0.01 level.

Spearman's Rank Correlation (P) was estimated to study the correlation between the psychophysical and physiological DLI. As shown in table4, analysis revealed a high positive correlation between the two. Correlation was estimated separately for the DLI obtained using strict and lineant criteria vs. DLI obtained physiologically using MMN. Psychophysical DLI obtained using both the methods correlated highly with physiological DLI. However, the correlation coefficient was higher between DLI estimated using lineant criterion and that obtained using MMN, especially at 40 dBSL. A 't-test' was also carried out to check the significance of the correlation obtained. Analysis revealed the correlation co-efficient to be highly significant at 0.01 level.

As mentioned earlier in this section, the DLI estimated physiologically was lower than that estimated psychophysically. Closer inspection of the data revealed that out of the 19 subjects, 14 had physiological DLI lower than that estimated using a strict criterion psychophysically, at both presentation levels. The remaining 5 had physiological DLI equal to that of the psychophysical DLI obtained using strict criterion.

Out of the 14 subjects who had physiological DLI lower than psychophysical DLI estimated using a strict criterion, 6 subjects had physiological DLI lower than and 8 had DLI equal to that estimated using a lineant criterion at 10 dB SL. However, at 40 dB SL, the no. of subjects with physiological DLI lower than that estimated psychophysically, using a lineant criterion was greater i.e. 9 had DLI's estimated using MMN lower than and 5 had DLI equal to that estimated using a lineant criterion psychophysically as seen in table-2.

Table-2 : Number of subjects with physiological DLI = or lesser then psychophysical DLI using strict and lineant criteria at 10 dB and 40 dB SL.

Level dBSL	Number of subjects (strict criterion)		Number of subjects (Lineant criterion)		Level dB SL
	MMN DLI < sub.DLI	MMN DLI = sub DLI	MMN DLI < sub DLI	MMN DLI = sub DLI	
10			6	8	10
40	14	5	9	5	40

Considering the results obtained by correlational analysis and the results that the physiological DLIs were lower than or equal to the psychophysical DLI obtained using a lineant criterion, it could be concluded that the psychophysical DLI using a strict criterion, in fact, does not depict the auditory systems actual capability to discriminate intensity differences. Also, the finding that the physiological DLI was equal to or lower than the psychophysical DLI estimated using lineant criterion highlights the fact that physiological DLI does depict the auditory systems actual capability to discriminate intensity differences. The results of the present study also highlight the differences between the passive and active perception of intensity differences. MMN, which reflects the passive perception of intensity different by the auditory system, traced DLIs to levels lower than that obtained by using psychophysical procedures. The psychophysical procedures reflect the active perception of intensity differences by the auditory system. This active discrimination of stimulus differences, in general, is affected by a lot of subjective factors, whereas the MMN, on the other hand reflects a brain process which is automatic in contrast to controlled information processing (Sams, et al. 1985). Also, automatic processing is characterized as fast, fairly effortless parallel processing which is not under direct subjective control (Schneider, et al. 1984). Thus, the DLI obtained using MMN, reflects the passive processing of the stimulus difference. Since the DLI estimated are lower than that estimated using psychophysical active discrimination procedures, MMN can indeed be used as an objective measure of DLI which in turn would reflect an individual's actual capability to discriminate intensity deviances. Moreover, since the subjective factors involved during MMN recording are also meagre, it can be considered for measuring/measurement of passive discrimination on which active discrimination is based.

b) **Effects of Presentation Level of Stimulus**

The effect of intensity of the stimuli on the DLI obtained psychophysically and physiologically was evaluated. Also the effects of the stimulus intensity on the latency, amplitude and duration of MMN were studied MMN's recorded for 3 dB deviance at 10 dB SL and 40 dB SL were considered to evaluate the effect of intensity on MMN.

As depicted in table-2, there was an increase in the number of subject's who had physiological DLI lower than the psychophysical DLI obtained using a lineant criterian with increase in the presentation level. The psychophysical DLI obtained, showed a decrease in the DLJ with increase in the presentation level as seen in table-1. This trend was seen for both the lineant and strict criteria. The physiological data also followed a similar trend with mean DLJ being smaller/lesser at 40 dB SL than at 10 dB SL. From this it can be concluded that the physiological DLI also confirms to the "near miss to Weber's law" as reported in psychophysical studies.

A non-parametric 't' test was carried out to check if this effect of the presentation level of stimulus on MMN thus, latency, amplitude and duration for 3 dB deviance was statistically significant. Results indicated that there was no significant difference between latency, amplitude and duration of MMN at 10 dB SL and 40 dB SL as seen in table-3. The result that there was no difference between the latency of MMN at 10 dB SL and 40 dB SL.

Table-3: Results of non-parametric 't' test for latency, amplitude and duration between 10 dB SL and 40 dB SL at 3 dB deviance.

S.No.	Deviance	Latency (ms)		Amplitude (uV)		Duration (ms)	
		l0dBSL	40dBSL	10 dB SL	40 dBSL	10 dBSL	40 dBSL
1	3dB	150.74 (34.88)	161.24 (42.99)	-2.50 (0.67)	-2.10 (1.03)	63.99 (20.48)	60.00 (25.11)
		P> 0.05		P>0.05		P>0.05	

This is in accordance to the finding of Sivaprasad and Iyengar (2000). The results of the present study conforms hypothesis of Sivaprasad and Iyengar (2000) that latency of MMN is not affected significantly by stimulus parameters. They have however reported of there being a significant difference in the amplitude of MMN. The present study's results are in contradiction to their findings on amplitude. This could be attributed to methodological factors i.e. Sivaprasad and Iyengar (2000) compared latency and amplitude for a deviance of 5 dB, whereas in the present study, this was done at 3 dB. To investigate if this could be a reason for differential results, a non-parametric 't' test was also carried out to see if there was a difference in the latency, amplitude and duration values for different deviations between 10 dB SL and 40 dB SL. Results revealed no significant difference between the MMN parameters evaluated for different deviances between 10 db SL and 40 dBSL.

Thus, the deviance per se cannot be attributed to be the cause of the difference between Sivaprasad and Iyengar (2000)study and the present study. However, another factor which could be the cause of the disparity is the range of presentation levels used in both the studies. Sivaprasad and Iyengar (2000) had three intensity levels (viz.) 25 dB SL, 45 dB SL and 60 dB SL. There was an increase in amplitude of MMN at 60 dB SL when compared to 25 dB SL only and this was statistically significant. In the present study, however intensity difference between the two levels i.e. 10 dB SL and 40 dB SL was lesser as compared to 25 dB SL and 60 dB SL. The results of the present study are also in contradiction to that reported by Schroger (1996) who reported of there being an increase in the amplitude of MMN with increase in stimulus intensity in an intensity change paradigm. This could be attributed again to methodological reasons. The findings of the present study i.e. no effect of stimulus presentation level on amplitude of MMN are in concurrence with the findings of Schroger (1994) who reported of there being no effects of supraliminal intensity on MMN for frequency discrimination paradigm.

Thus, the presentation level of the stimulus did show effects on both psychophysiological and physiological DLI i.e. decrease in DLJ with increase in intensity level. However, there was no significant effect of intensity level on the latency, amplitude and duration of MMN.

c) **Comparison of MMN at Different Deviances**

The latency, amplitude and duration of MMN were compared at different deviances at both 10 dB SL and 40 dB SL. The table-4 represents the mean values and standard deviations for various deviances at 10 dB SL and 40 dB SL.

Table-4: Mean and SD's for MMN latency, amplitude and duration for different deviances at 10 dB SL and 40 dB SL.

Devi-ance (dB)	10dBSL				40dBSL			
	N	Latency (ms)	Amplitude (uV)	Duration (ms)	N	Latency (ms)	Amplitude (uV)	Duration (ms)
1	9	176.11 (41.28)	-2.16 (1.01)	59.44 (14.43)	6	172.73 (27.59)	-2.60 (0.56)	60.65 (19.76)
2	12	170.70 (40.70)	.227 (0.79)	72.55 (30.10)	12	162.38 (38.79)	-2.43 (1.29)	64.09 (20.79)
3	14	150.74 (34.88)	-2.50 (0.67)	63.99 (20.48)	17	161.24 (42.99)	-2.10 (1.03)	60 (25.11)
4	11	130.20 (36.62)	-2.04 (1.11)	69.31 (15.09)	10	153.47 (133.76)	-2.16 (1.15)	61.70 (12.38)
5	4	132.96 (53.78)	-2.11 (0.78)	66.19 (32.06)	9	156.63 (53.50)	-1.98 (0.80)	66.79 (24.50)
6	3	109.34 (24.64)	-1.75 (0.29)	86.69 (9.50)	2	103.10 (38.66)	-2.01 (1.81)	64.02 (25.44)

As can be noted from the table, there was some sort of trend noticed in the latency values of MMN at different deviances. The latency showed an increasing trend with decrease in the deviance i.e. as the intensity deviance became smaller, the latency of the MMN increased. This finding clearly highlights the fact that closer the two stimuli are in terms of intensity [(i.e.) smaller deviance], the greater is the time required to process this deviance by the sensory memory. This greater processing time is reflected in a prolonged latency. Another observation made was that with smaller deviances, the morphology of MMN also became poor (Fig.l). However, when the deviance is large, the detection of this deviance is faster and easier and hence shorter latencies are observed for greater deviances. Also, with greater deviances, MMN morphology was better and easily identifiable (Fig. l) . Such a trend, however, was not observed for amplitude and duration of MMN. This could be explained by putting forth an hypothesis that amplitude and duration of MMN are dependant on the intensity of the sensory memory trace for a given deviance and not the deviance per se.

A non-parametric 't' test was carried out to check if there was any significant difference between the latency, amplitude and duration of MMN among different deviances at 10 dB SL and at 40 dB SL separately. Results revealed no significant difference between the deviances for latency, amplitude and duration at both 10 dB SL and 40 dB SL ($P<0.05$ and $P<0.01$).

The finding that there was no significant difference in the latency, amplitude and duration values for different deviances at both presentation levels and also the finding that the MMN parameters for different deviances were not different significantly, can be explained by a hypothesis put forth by Schroger (1996). He states that the neural representations or the sensory memory traces underlying MMN are merely sensitive to a change in the information content and not to the absolute amount of stimulus energy per se. If MMN was influenced by intensity of the stimulus then there would have been a significant difference, atleast in the amplitude of the MMN between 10 dB SL and 40 dB SL. Moreover, there also would have been a difference between MMN parameters for different deviances at both the presentation levels. However, as already reported, both these findings were not found in the present study.

4.9 (a).

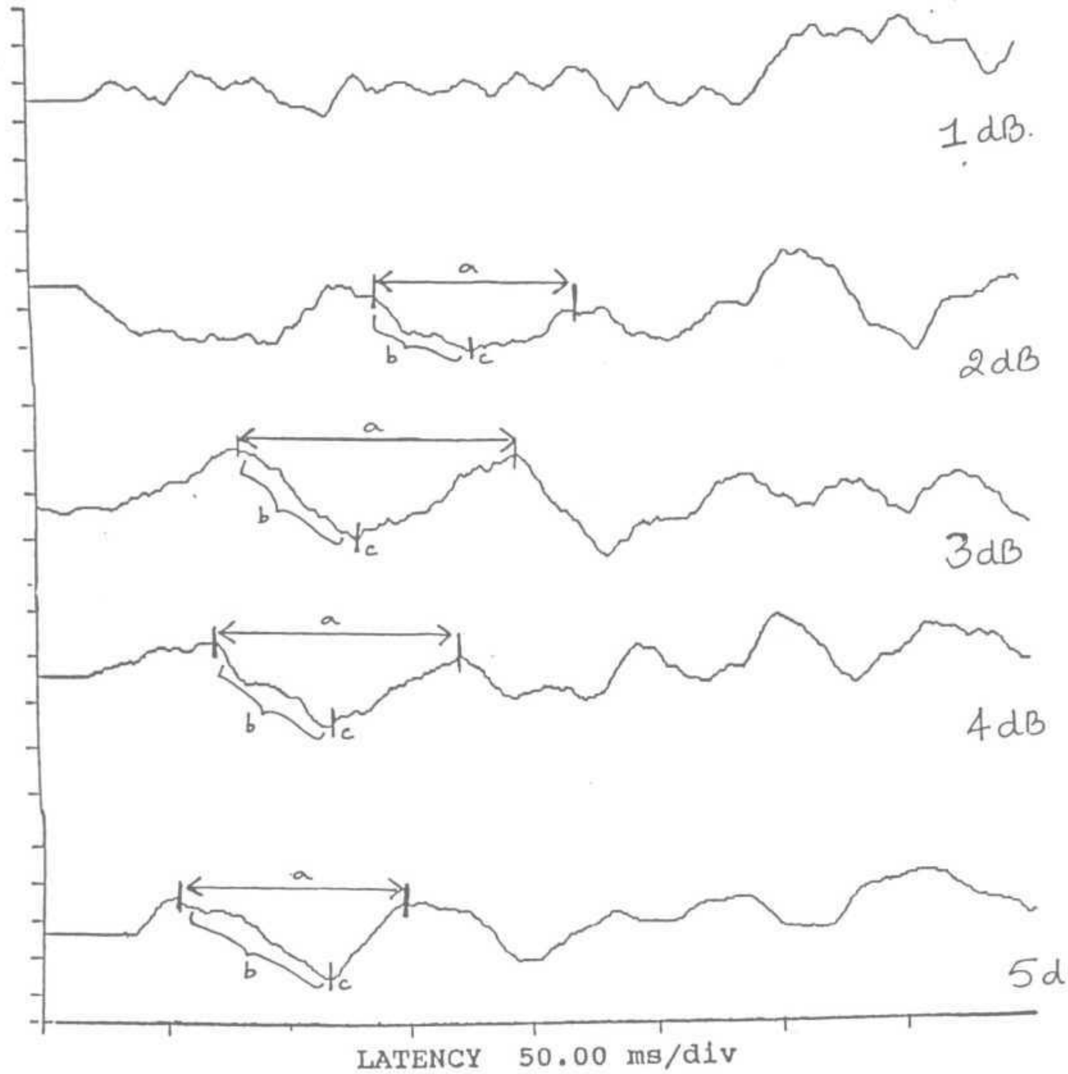


FIG 1(a): MMN WAVEFORMS FOR DIFFERENT DEVIANCES AT 10dBSL

DEVIANCE	LATENCY (ms) (c)	AMPLITUDE (μV) (b)	DURATION (ms) (a)
5 dB	114.03	−4.30	100.75
4 dB	114.81	−3.69	77.31
3 dB	125.74	−2.71	114.03
2 dB	174.16	−2.99	87.48
1 dB	— not seen —	— not seen —	

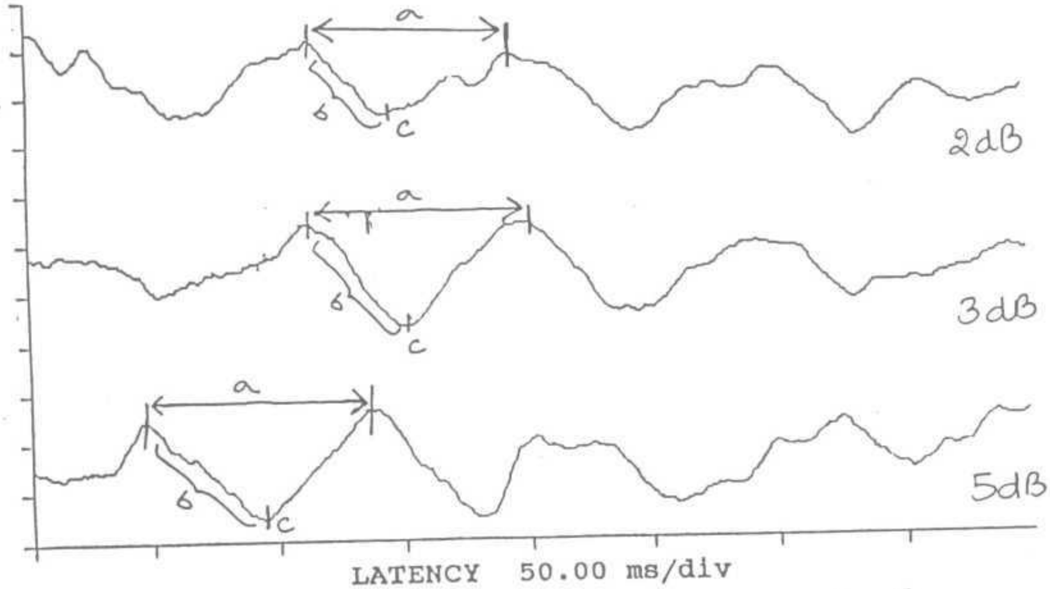


FIG 1 (b): MMN WAVEFORMS FOR DIFFERENT DEVIANCES AT 40dBSL.

DEVIANCE	LATENCY (ms) (c)	AMPLITUDE (μV) (b)	DURATION (ms) (a).
5dB	92.47	-2.43	87.48
3dB	152.28	-4.59	81.25
2dB	141.47	-2.63	63.26

The result that the intensity of the stimulus did effect the psychophysiological DLI is in accordance with the results of psychophysiological studies on DLI (Carlyon and Moore, 1984; Florentine et al. 1987). However, the presentation level of stimulus did not have any effects on the MMN parameters, especially the amplitude which reflects automatic (sensory) change detection. Therefore, the amplitude of MMN at a particular deviance cannot be considered to predict in any way the discrimination ability of an individual i.e. based on the amplitude of MMN at a particular deviance, it cannot be said whether the DLI would be lesser than or greater than that deviance. This was speculated by observing individual data i.e. amplitude of MMN at different deviances till the physiological DLI. The amplitude did not show any particular trend for deviances at both 10 dB SL and 40 dB SL and for this is further strengthened by the finding that MMN amplitude failed to show any trend with respect to different deviances at both presentation levels as a group also (Table 4-)-

Thus, the results of the present study clearly indicate MMN can be used as an objective method for estimating DLI of an individual. Results also suggest that prediction of an individual's DLI cannot be made depending on the amplitude of MMN at any one given deviance and also that the intensity level of the stimulus had no significant effect on the latency, amplitude and duration of MMN.

SUMMARY AND CONCLUSION

The human ear, apart from being extremely sensitive to a wide range of stimulus intensities and frequency is also able to detect/ discriminate small differences in a wide range of stimuli. The smallest perceivable difference between two sounds is called the differential limen (DL) or just noticeable difference. Psychophysical methods are used to determine the DLL However, these involve a lot of subjective factors and methodological differences.

Recently Mismatch Negativity (MMN) has been recorded for a difference between standard and deviant stimuli (Sams et al. 1985) and also for deviances near to the DL or jnd (Picton, 1995) in an "oddball paradigm". It provides an automatic response that can be used to study attention independent processing involved in auditory sensory memory and detection of an acoustic change (i.e. change detection).

The present study was taken up in an attempt to see if there was a correlation between the psychophysically established DL for intensity (DLI) and physiologically derived DLI using MMN. Another aim was to study the effects of presentation level of the stimulus on MMN latency, amplitude and duration. The effects of different deviances on MMN latency, amplitude and duration were also evaluated.

Twenty normal hearing subjects (10 M, 10 F) were taken for the study. The psychophysical DLI was established at 1000 Hz using "yes-no" procedure for two criteria (Hz) a strict criterion and a lineant criterion at 10 dB SL and 40 dB SL. The physiological DLI was established as the minimum deviance for which MMN could be recorded at both presentation levels in an intensity discrimination paradigm. The frequency used was 1000 Hz for both standard and deviant stimuli.

MMN waveforms were analysed in terms of the latency, amplitude and duration. The lowest level at which MMN could be recorded was also tabulated and the data were subjected to statistical analysis.

Results revealed that -

a) There was a high positive correlation between psychophysical DLI established using both criteria and the physiological DLI.

b) The correlation between psychophysical DLI and physiological DLI was higher for DLI established using a linsant criteria (psychophysically) and was greater at 40 dB SL than at 10 dB SL.

c) The physiological as well as psychophysical DLI were smaller at 40 dB SL than 10 dB SL suggesting a decrease in DLI with increasing intensity level.

d) Physiological DLI traced using MMN was smaller than the psychophysical DLI.

e) The presentation level had no effect on MMN latency, amplitude and duration.

f) There was no significant difference in latency, amplitude and duration for different deviances at 10 dB SL and 40 dB SL.

Thus based on the results of this study it can be concluded that -

a) MMN can be used as an objective method to measure DLL

b) Presentation level of the stimulus has no effect on MMN latency amplitude and duration.

c) Deviances do not affect the MMN latency, amplitude and duration at both the presentation levels.

<u>Suggestions for further research</u>

1. Needs to be carried out on a larger population for generalization.
2. Wider range of presentation level could be used.
3. Needs to be done on pathological population.
4. Needs to be done at frequencies other thanl kHz.
5. Physiological DL for other parameters viz., frequency duration etc. could be investigated on the same lines.

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