Physiological Correlates of Masking Level Difference

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Abstract

The present study aimed to check, whether the late latency potentials can be used as a tool to measure electrophysiological masking level difference. If so, what is the relationship between electrophysiological masking level difference and behavioral masking level difference? A total of thirty subjects were taken in the study. Age ranged between 18 and 40 years with a mean age of 24.2 years were included. All of them had hearing thresholds within normal limits. Stimuli for Electrophysiological Masking Level Difference (EMLD) were generated using Matlab R2009a. Both EMLD and Behavioral Masking Level Difference (BMLD) were recorded using bracketing method. 'P2' latency for both SoNo and SπNo conditions were compared to check for significant difference. Both EMLD and BMLD values were compared and checked for correlation. Peak latencies of 'P2' were significantly different for both SoNo and SπNo condition. Mean values of EMLD and BMLD procedures show no significant difference. There is a significant positive correlation between EMLD and BMLD. MLDs recorded from ALLRs conceded similar magnitude as that obtained from behavioral measures. Since, there was a positive correlation between the EMLD and BMLD, Auditory Evoked Potentials can be used to obtain MLD in difficult to test population to assess functioning of auditory nervous system.

Keywords: *Electrophysiological masking level difference, behavioral masking level difference, late auditory evoked responses, release of masking.*

Introduction

The phenomenon of masking level difference (MLD) for pure tones was first described by Hirsh (1948), which is known to be a psychoacoustic phenomenon that compares masked thresholds in a number of signal and noise phase conditions. A commonly used paradigm involves the subtraction of threshold to signal 180^0 out of phase and noise in phase at the two ears (SπNo) from the threshold to signal and noise in phase at the ear (SoNo). A paradigm where subtraction of threshold to signal in phase at the two ears and noise 180^0 out of phase at the ears (SoNπ) from the threshold to signal in phase and noise in phase at the two ears (SoNo) results in relatively lesser amounts of release from masking.

The magnitude of the threshold differences (release from masking) is inversely related to signal frequency i.e, as the frequency of signal increases the MLD decreases (Hirsh, 1948; Durlach, 1963). Also, as the noise bandwidth increases the MLD decreases (Hall & Harvey, 1984). Whereas, MLD is directly related to signal level (Hirsh, 1948; McFadden, 1968). The amount of masking release also reduces as the interaural phase disparity of either the signal or the masker is decreased (Colburn & Durlach, 1965; Jeffress, Blodgett & Deatherage, 1952). The dependence of MLD on interaural phase relationships is largest at low frequencies.

MLD using an electrophysiological approach was first put forward by Kevanishvili and Lagidze (1987). Study by Fowler and Mikami (1995), investigated to find a correlation between behavioral MLD and an auditory brainstem responses with opposite polarity high frequency (4000 Hz) and low frequency (500 Hz) tone pips. They suggested that the ability to maintain phase information along the brainstem is necessary but not sufficient to generate the masking level difference.

Kevanishvili and Lagidze (1987) compared the 'Pa-Nb' responses elicited by 60 dBSL in SoNo and SπNo conditions for 580 Hz tone bursts and reported that the latencies and amplitudes of Pa-Nb were not significantly different in these two stimulus conditions. Galambos and Makeig (1992) concluded that the 40 Hz Auditory Steady State responses (ASSR) does not show the binaural MLD; however the study considered results from only two subjects (one with hearing loss). Also reported that, the Binaural MLD is only obtained for the slow cortical auditory potentials (waves N1-P2) and not for the auditory brainstem responses (ABR) or the middle latency responses (MLR) (Fowler & Mikami, 1992) and inferred this to be because, ABR and MLR may reflect the neural pathways from the

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cochlear nuclei to the inferior colliculus that bypass the superior olivary complex.

The late auditory evoked potential MLD has been shown to have several characteristics similar to behavioral MLD (Fowler & Mikami, 1992). First, inverse relation of MLD magnitude to signal frequency. Second, the late auditory potential MLD is larger with narrow band (50 Hz wide) noise than for wide band (600 Hz wide) noise (Fowler & Mikami, 1992). Third, the absence of phase dependent threshold differences in quiet indicates that the late potential MLD requires the presence of background masking noise (Fowler & Mikami, 1992; Kevanishvili & Lagidze, 1987).

The Electrophysiological masking level difference (EMLD) can be recorded in two possible ways (Fowler & Mikami, 1992). First, Stimuli in SoNo condition are reduced in level until the late potentials 'P2' disappears. Then the stimuli are switched to SπNo condition, which causes a large potential 'P2' to reappear at the threshold level for the SoNo signals. This amplitude difference for SoNo and SπNo signals at the threshold level for SoNo signals is considered as MLD like phenomenon. Second, the actual signal level for threshold for both SoNo and SπNo are determined and difference in the two thresholds can be considered as EMLD and compared directly to the behavioral MLD to check for correlation (Fowler & Mikami, 1992). The present study considered the latter procedure to arrive at electrophysiological masking level difference.

A large number of studies are devoted to the MLD which is based on psychoacoustic measurements (Durlach & Colburn, 1978). The auditory evoked potentials appear to be an alternative tool for reliable investigation of MLD phenomena. Electrophysiological MLD would further provide clarification of the mechanisms of the MLD (Durlach & Colburn, 1978). Hence, in the current study auditory late latency responses (ALLR's) were selected and an effort to validate the findings that, it would yield MLD like phenomenon has been assessed. The earlier study (Jerger & Hannley, 1983), ignored the effect of peripheral hearing loss on MLD, or used a white noise which is known to yield lesser amounts of MLD (Hall & Harvey, 1984). Therefore, in this study care was taken to ensure that all participants are devoid of peripheral hearing loss and narrow band noise was used to mask the signal. Thus, the present study aimed to check, whether the late latency potentials can be used as a tool to measure electrophysiological masking level difference. If so, what is the relationship between electrophysiological masking level difference and behavioral masking level difference?

Method

Subjects

A total of thirty subjects participated in the study. Age of the subjects ranged between 18 and 40 years with a mean age of 24.2 years. The behavioral thresholds of all subjects were within 15 dB HL at all frequencies from 250 Hz to 8 kHz and 250 Hz to 4 kHz for air conduction and bone conduction respectively in both ears. All subjects had "A" type tympanograms with normal acoustic reflex thresholds in both ears. All of them had normal click evoked-ABR at lower (11.1/sec) and higher (90.1/sec) repetition rate, indicating absence of retro cochlear pathology (RCP). None of them reported to have any history of neurological or otological problems. No physical illness on the day of testing was reported by the subjects.

Instrumentation

A calibrated diagnostic audiometer, (Interacoustics-AC 40) with TDH-39P earphones was used for estimating the air conduction thresholds. Radio ear B-71 bone vibrator was used for bone conduction testing. The same audiometer was also used to obtain MLD behaviorally. A calibrated middle ear analyzer, (GSI tympstar) was used to record tympanogram and acoustic reflexes. Intelligent Hearing Systems (IHS) SmartEP windows USB version 3.95 was used to record auditory evoked potentials and also to obtain MLD electrophysiologically. Stimuli to obtain MLD electrophysiologically were generated using a personal computer installed with MATLAB R2009a software.

Stimulus Generation

Stimuli for EMLD were generated using program implemented in MATLAB R2009a. Tone burst generated was a pure-tone of 500Hz with 250 ms duration and 20 ms rise and fall time was generated with 44.1 kHz sampling frequency and 16 bit A/D conversion, which became an in-phase signal (So). For anti-phasic condition (Sπ), a phase delay of 180^o was provided by calculating delay in number of samples between 0^o and 180^o. The portion of the signal between 0^o and 180^0 was made zeros (silence) in the in-phase signal, which provides the anti-phase signal or Sπ i.e., phase delay signal. During the process of generating anti-phasic signal, duration of the signal was kept constant.

On the other hand NBN with a center frequency of 500 Hz was generated as described by Stelmachowicz and

Jesteadt (1984). Random noise of 10 minutes duration was generated at a sampling rate of 44.1 kHz. A Fourier Transform was applied to the random noise, and all the frequency components above 50 Hz were set to zero amplitudes. An inverse Fourier transform was then applied to obtain the time domain low pass filtered noise with cut-off frequency of 50 Hz, as shown in Figure 1. A sine wave of 500 Hz with duration of 10 minutes was generated at a sampling rate of 44.1 kHz using the following equation:

$$\text{Sine wave} = A*\sin(2\pi\times f\times t)$$

where 'A' represents amplitude, 'f' indicates frequency and 't' indicates time.

This sine wave was then multiplied with the low pass filtered noise to obtain a 500 Hz narrow-band noise with 100 Hz bandwidth and very steep frequency skirts on either side of the spectrum shown in Figure 2. The intensity of narrowband noise was varied in 2 dB steps from 40 dB SPL to 90 dB SPL. The narrowband noises were played using adobe audition Version 3 software program, through an EarTone-5A insert receiver driven by a standard PC sound card. The output intensity of the inserts was calibrated.

The tonal stimuli were fed to IHS EP system which ran on advanced research module protocol to record AEPs. The tones were converted into STIM format using the proprietary IHS STIMCONV module version 3.9. They were played using IHS EP system through an EarTone-3A insert receiver. To present the tone and noise in in-phase and anti phasic conditions, the output of the two-inserts was coupled to a foam-tip, to deliver the tone and noise binaurally. SπNo stimuli configuration was generated rather than SoNπ configuration as the former configuration yield better MLD than the latter one (Aithal, Yonovitz, & Dold, 2006).

Procedure

All the tests were carried out in a well illuminated air conditioned rooms which were acoustically treated. The noise levels were within the permissible levels as recommended by ANSI-S.3 (1991). To record EMLD the subjects were instructed to sit comfortably and relax on a reclining chair facing away from the instrument. They were instructed to avoid head, eyes, neck and limb movements during testing, to avoid artifacts.

Electrode placement: The non-inverting electrode placed on the Vertex (Cz), inverting electrode placed on tip of the nose since, it is highly active and ground electrode was placed on low forehead (Fpz). ER-3A Insert ear phones were placed in the ear canal to present the tone and ER-5A insert ear phones were used to present noise. The parameters used to record Late Auditory Evoked Potentials are given in Table 1.

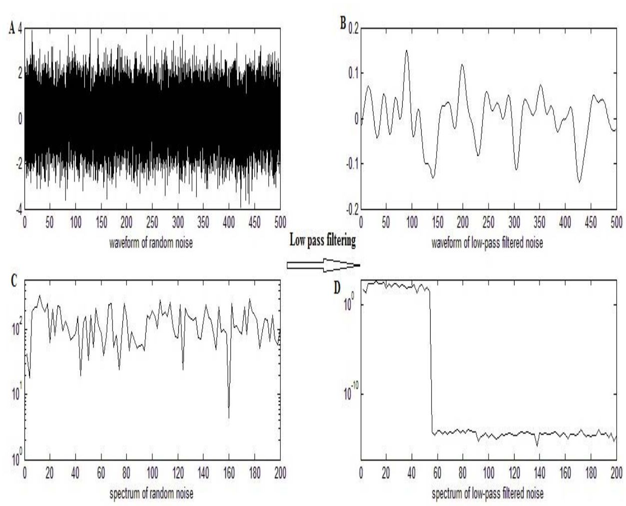

Figure 1: Waveform of a random noise (A), waveform after low pass filtering of random noise (B), spectrum of random noise (C) and spectrum of random noise after low pass filtering (D).

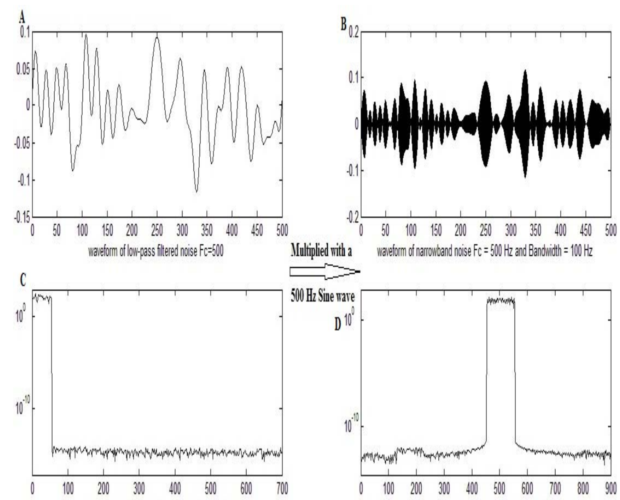

Figure 2: Waveform of low pass filtered noise (A), waveform of 500 Hz narrowband noise with a bandwidth of 100 Hz wide (B), spectrum of low pass filtered noise (C), spectrum of 500 Hz narrowband noise with a bandwidth of 100 Hz wide (D).

Table 1: Parameters used to record Late Auditory Evoked Potentials

Acquisition parameters		Stimulus parameters	
Filter	HPF: 1 Hz LPF: 30 Hz	Transducer	ER-3A Insert earphones (300Ω) for 500 Hz toneburst and ER-5A for 500 Hz NBN
Analysis epoch	600 ms	Stimulus	500 Hz toneburst for So and Sπ with 500 Hz NBN
Artifact rejection	50 µV	Polarity	Rarefaction
Notch Filter	Off	Intensity	70 dBSPL
Amplification	50,000	Stimulation rate	1.1/sec
Data points	1025	Duration of stimulus	250 ms with 20 ms rise/fall time
Sweeps	500	Sweeps	500

Recording of Electrophysiological MLD (EMLD): Evoked potential was recorded in an acoustically and electrically shielded room. Subjects were asked to be awake throughout the recording and informed the clinician in case they feel drowsy. Since any state of drowsy or sleep might affect the amplitude and morphology of late auditory evoked potentials. Subjects were instructed to fixate their vision towards the screen where subtitled movie was played. Thresholds were estimated considering the presence or absence of wave 'P2' of auditory late latency responses for 500 Hz tone burst. In the present study wave 'P2' was considered as the marker for presence of late auditory potentials since, wave 'P2' of auditory late latency responses (ALLR) are more evident in adults than children (Ponton, Don, Eggermont & Masuda. 1996). Noise had the same phase as the signal phase (No) was then introduced and the level of noise was gradually increased in 2 dB steps such that the wave 'P2' disappeared. The lowest masker level at which wave 'P2' just disappeared was noted. This masker level served as threshold for SoNo condition. Then, the 500 Hz tone burst was made out of phase and presented without changing the intensity level, which yielded in reappearing of wave 'P2'. Now, noise level was once again increased (reducing the SNR), till the point at which wave P2 disappeared. This masker level served as threshold for SπNo condition. Difference in thresholds between SoNo and SπNo conditions was considered as the EMLD. Each condition was repeated to ensure replicability. Thresholds were judged by an experienced audiologist without the knowledge of the stimulus conditions.

Recording of Behavioral MLD (BMLD): Subjects were made to wear TDH-39P supra aural headphones with ear cushion (MX-41/AR) to ensure the comfort and were instructed to respond for the presence of tone every time they hear. A 500 Hz signal and 500 Hz NBN are presented in both homophasic (SoNo) and antiphasic (SπNo) conditions to measure Behavioral binaural masking level difference.

Initially, thresholds for tonal stimulus were obtained using bracketing method. Tone level was set to a 70 dB SPL and noise was presented below 70 dB SPL. Both were presented with a same phase on both the ears. Noise level was gradually increased in 2 dB steps till the tone was just completely masked. This was considered as the masked threshold in SoNo condition. At this point, tone was made out of phase which yielded in perception of tone again. Now, noise level was further increased in 2 dB steps to mask the tone and masked threshold is obtained. This masker level served as threshold in SπNo condition. Difference in thresholds between SoNo and SπNo conditions was considered as the BMLD.

Results and Discussion

Peak latency of 'P2' at minimum signal to noise ratio in SoNo condition were analyzed to compare with the peak latency of 'P2' at minimum signal to noise ratio in SπNo condition. EMLD values were computed and mean and standard deviation (SD) values were obtained. BMLD values were computed and mean and standard deviation (SD) values were calculated. Finally, the correlation between EMLD and BMLD was evaluated using SPSS Version 17 software package.

Computation of 'P2' Latencies in both SoNo and SπNo

From the Table 2 it can be observed that mean 'P2' latency at minimum SNR was slightly shorter for SoNo condition than SπNo condition. To assess whether 'P2' latency between two conditions reaches significance level or not, a Paired t-test was carried out. Results revealed significant difference between 'P2' latency obtained at the thresholds of SoNo and SπNo conditions.

The significant difference in latencies of 'P2' between SoNo and SπNo condition obtained in the study is in general agreement with previous studies which used late auditory potentials (Fowler & Mikami, 1992a, 1992b, 1996; Yonovitz, Thompson & Lozar, 1979). Yonovitz, et.al., (1979) reported that the latency and amplitude of wave 'P2' are slightly longer and larger respectively in SπNo condition than compared to SoNo condition. However, in the earlier study by Kevanishvili and Lagidze, (1987) reported that the latencies of 'P2' are shorter for SπNo condition than SoNo condition. Unlike, in the present study the mean 'P2' latencies for SπNo condition is longer than SoNo condition.

The possible reason for prolongation of 'P2' latency in SπNo condition could be, in case of out of phase condition i.e., SπNo, the quantity of neural units responding to the signals is increased than for SoNo condition. So, during the release of masking there will be significant increase in neural units resulting in an intensification of the neural interconnections, as a result of both temporal and spatial integration processes, hence, the wave 'P2' may get broader yielding slight increase in latency. In the earlier study by Kevanishvili and Lagidze (1987), the 'P2' latency measures were carried out by varying the signal level keeping the noise level constant unlike in the present study, which might have decreased the mean latency of 'P2' in SπNo condition.

Computation of EMLD and BMLD

ALLRs were obtained in different conditions i.e., without noise, SoNo and SπNo conditions having a signal level of 70 dB are shown in Figure 3.

As it can be seen in Figure 3, ALLR recorded in quiet condition at 70 dB SPL had very good wave morphology showing clear N1-P2 and P2-N2 complex. However, the morphology degraded at the threshold for two different conditions though the signal level was constant. The waveform became significantly poor and P2-N2 complex were not clearly observable.

EMLD and BMLD were calculated for thirty subjects. Mean (M), standard deviation (SD), and range are given in Table 3. Paired t-test was administered to check for the significant difference between EMLD and BMLD. The results indicated that there is no significant difference between EMLD and BMLD values. The details of the t-test results are given in Table 3.

In the present study the mean values of both EMLD and BMLD showed no significant difference. The findings of the present study are in consonance with the earlier studies (Kevanishvili & Lagidze, 1987; Fowler & Mikami, 1992a, 1992b, 1996, Yonovitz, et.al., 1979). Previous Studies (Kevanishvili & Lagidze, 1987; Yonovitz, et.al., 1979) compared the EMLD values with the BMLD values and reported that the magnitude of EMLD showed no difference when compared to BMLD values.

Table 2: Mean and standard deviation of 'P2' latency, t-test results between the two conditions

P2	Mean (ms)	Standard deviation	t- value	Degrees of freedom (Error)	Significance
SoNo condition	193.19	32.9	5.83	29	0.00
SπNo condition	226.99	27.2			

Table 3: Mean, SD, range and t-test values of EMLD and BMLD

Tests	Mean (M)	Standard deviation (SD)	Range	t- value	Degree of freedom	Significance
EMLD	11.33	4.96	0 - 22	1.05	28	0.30
BMLD	11.79	2.28	8 - 16			

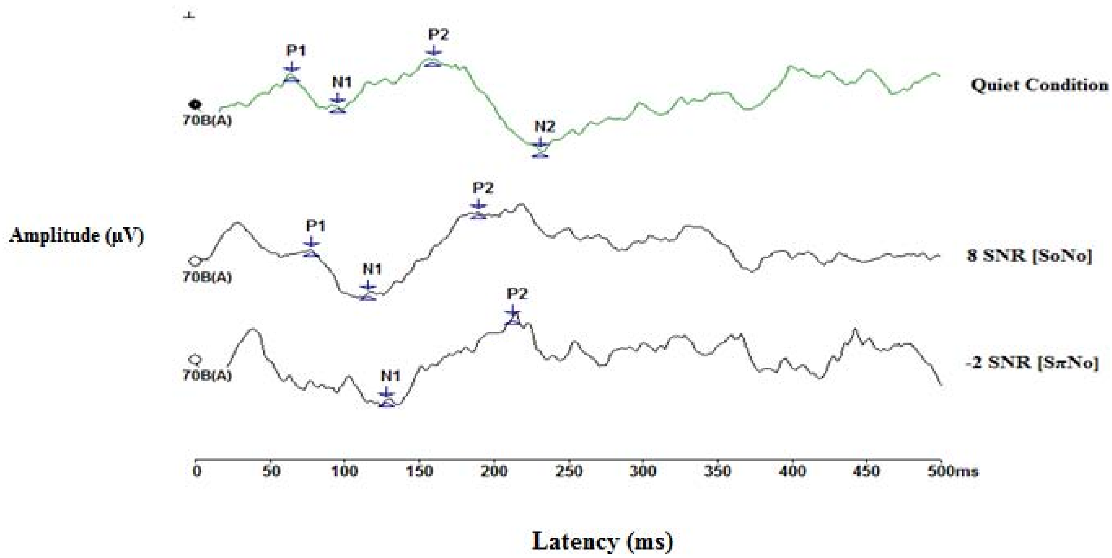

Figure 3: Illustration of Late auditory evoked potentials depicting masking level difference of 10 dB.

The EMLD values of the present study are comparable with the BMLD values. Study by Fowler and Mikami (1996) reported that EMLD values with 'P2' measures on SπNo and SoNo condition were 11 dB and for behavioral measures with same stimulus phase condition it was around 8 dB. 'P2' measures derived from the EMLD shows similar magnitude with that derived from the behavioral measures. They suggested that the encoded phase information from lower structures in the auditory pathways is translated to threshold differences cortically by the generators of the late potentials. The late potential findings, therefore, suggest a role of the cortex in the production of the EMLD, which is in agreement with the conclusions of Cranford, Stramler, and Igarashi (1978), wherein the authors examined the effect of unilateral and bilateral ablation of neocortex in cats on binaural MLD test, and reported that the MLD phenomenon is not exclusively cortical dependent but also dependent on the subcortical structures (Superior olivary complex).

However, study by Wong and Stapells (2004) reported that auditory steady state responses (ASSRs) showed significantly lesser MLDs than Electrophysiological procedures which considered 'P2' measures. However, they also reported cortical ASSRs showed relatively higher degrees of MLD than brainstem ASSRs did. But the overall MLD on Cortical ASSRs was significantly lesser than Behavioral measures of MLD. These results suggest that the cortical ASSRs are not directly related to the slow cortical potentials ('P2'). The generator of the cortical potential 'P2' is different from the cortical ASSRs (Wong & Stapells, 2004). Hence, it may not be concluded that all cortical potentials yield MLD like phenomenon.

Correlation between EMLD and BMLD to check the relationship

To obtain the relation between the EMLD and BMLD, scatter plot was obtained. The individual EMLD and BMLD values are displayed in Figure 4.

From the scatter plot, it is clearly evident that there is a significant positive correlation between EMLD and BMLD. This represents that for those subjects when the BMLD values have increased, EMLD values also increased. Figure 4 indicates 18 data points on the scatter plot even though the total numbers of subjects were thirty. The remaining twelve subjects showed similar amounts of MLDs in both electrophysiological and behavioral measures.

To find the relationship between the two variables such as EMLD and BMLD, Pearson's product – moment correlation co-efficient test was carried out. It was found that there is a significant positive correlation ($r=0.74$) obtained at 0.01 significance level, between the two conditions. This indicates that for those subjects in whom EMLD had increased, BMLD also increased.

The findings of the study regarding correlation between EMLD and BMLD are in general agreement with the previous studies (Fowler & Mikami, 1992a, 1992b, 1996, Yonovitz, et.al., 1979). Study by Yonovitz, et.al., (1979), reported a correlation coefficient of 0.9 which indicates that there is significant positive correlation between the two procedures. However, the comparison of the EMLD values is made with the BMLD values that were obtained by Hirsh (1948).

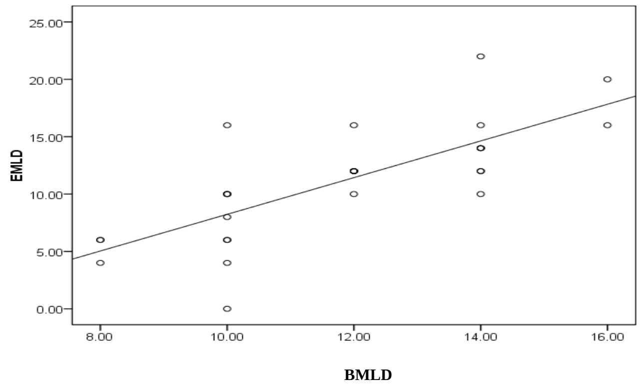

Figure 4: A scatter plot depicting the relationship between EMLD and BMLD across subjects.

Fowler and Mikami (1996), also reported a positive correlation with a SπNo and SoNo stimulus phase combination in both test procedures. The correlations between the two conditions were consistent only when ALLRs were used and not compared with ABRs and MLRs. The possible reasons could be due to the dependency of MLD phenomena on the spectral characteristics of the stimulus used to record ALLRs i.e., low frequency tone bursts were used unlike clicks in ABR (Yost, 1988; Durlach & Colburn, 1978). On the other hand, frequency specificity of ABRs and MLRs reflected an activation of high frequency neural constituents for the low frequency tone bursts (Kevanishvili & Lagidze, 1987). While, stimulus for ALLRs, in the present study considered tone bursts with longer rise and fall times (20 ms), concentration of the effective energy of the signals around the low frequency bands (i.e., 500 Hz), as a result, probably the frequency specificity of the ALLRs should have improved. Also, study by Yonovitz, et.al., 1979) reported reduction in EMLD magnitude when clicks are used to record ALLRs, than compared to the EMLDs recorded with tone bursts. Hence, it can be inferred that the positive correlation of EMLD with BMLD is more significant when both the procedures used similar acoustic parameters.

Conclusions

In the current study, it is shown that MLD can be recorded from the late auditory evoked potentials. Since, the magnitudes of MLD in both the procedures were significantly similar and positively correlated. Thus, the AEPs can be effectively used to record MLD in difficult to test population and also to assess auditory nervous system. The study also highlights the necessity of further study in clinical population. The study can be used to assess the effect of neural maturation on binaural interaction or developmental changes of MLD. The late auditory potential MLD may be developed into an objective research for assessing binaural function. It highlights the necessity of further study in clinical population.

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