Importance of Long Latency Responses in Pediatric Hearing Assessment

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APRIL 2007.

This is to certify that this dissertation entitled **"Importance of Long Latency Responses in pediatric hearing assessment"** is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student Registration no: 05AUD011. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Importance of Long Latency Responses in pediatric hearing assessment"** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled **"Importance of Long Latency Responses in pediatric hearing assessment"** is the result of my own study and has not been submitted earlier to any other university for that award of any degree or diploma.

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April 2007

Dedicated to...

My Grand Parents

My Beloved parents

My Brother & Sisters

My Bhania.... SAMAY

&

My dear Animesh Sir

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INTRODUCTION

Approximately 10% of newborns are at risk for medical problems and developmental disability. Most infants at risk, are detected either at birth as reflected in low APGAR scores, or during the complete physical examination within few hours of birth.

Different aspects of neurogenesis take place somewhat independently, yet simultaneously and interactively in infants. Degenerative and regressive events involving cell death, retraction of axonal process and elimination of synapses occur concurrently throughout development (as cited in Salamy, Eggermont, and Elredge, 1994). Literature on developmental outcomes of infants has shown that, at risk infants display increased susceptibility to a variety of physical and developmental deficits including hearing improvement.

Hearing is critical for normal speech and language development, which in turn is vital for most aspects of normal human development. A significant hearing impairment at birth can produce major disruption in language learning (Menyuk, 1977) and produce irreversible deficits in the development of central auditory pathways (Moore, 1985). Even a mild hearing impairment has been implicated in delayed development of auditory skills (Quigley, 1978). Early identification of hearing loss followed by appropriate management minimizes the auditory deprivation, which can interfere with speech and language learning and central nervous system maturation. So, early identification will waive off a number of problems regarding person's educational, social and economic development that may arise in future.

Hearing loss in children is silent, hidden disability. It is hidden because children, especially infants and toddlers, cannot tell us about their inability to hear well. However, there are several ways to identify hearing loss in infants. There are subjective and objective methods to identify hearing impairment. In infants and toddlers, such methods usually do not involve the subjects' active involvement. Most commonly used behavioral method is Behavioral Observation Audiometry (BOA) and the objective methods are Auditory Brain-stem Response (ABR), Oto-Acoustic Emissions (OAE) and the Immittance audiometry.

Galambos and Galambos (1975) found a drop in latency of the ABR peaks with age in the premature infants which they attributed to maturational changes. Roberts, Davis, Phon, Reichet, Sturtevants, and Marshall (1982) concluded that ABR failures in the infants in their study resulted mainly from immaturity. Raj, Gupta and Anand(1991) found on re-evaluation of 8 out of 13 infants with risk factors, who had failed on BAER earlier, had developed normal thresholds and by 6 months follow-up, only 3% had hearing loss. Misra, Katiyar, Kapoor, Shukla, Malik, and Thakur (1996) reported the BAER abnormalities and their reversibility in neonates with birth asphyxia.

It is evident that infants with risk factors likely to have varieties of abnormalities in auditory system which might vary from permanent severe hearing loss to normal hearing; reversible audiological test results in Auditory Maturational Delay (AMD) and Auditory Dys-synchrony (AD) of different degrees. An appropriate test protocol is essential to differentiate one pathological condition from other as it not only aids to the early appropriate rehabilitation it also adds to appropriate counseling to the parents.

Need of the study:

Before adopting concrete steps of appropriate medical, educational and audiological intervention, one major challenge posed for audiologist is to confirm the existence, type and degree of hearing loss in infants especially in high risk babies.

Most authors agree that from 2%-15% of infants with hearing loss may exhibit auditory neuropathy; that is, one can expect to identify auditory neuropathy in approximately 1-3 infants per 10,000 births (Ranee, Beer, Cone-Wesson, Shepard, Dowell, King, Rickards, & Clark, 1999; Sininger, 2002). The great majority of infants with auditory neuropathy exhibit one or more high risk factors, including blood transfusion, hyperbilirubinemia, anoxia, low birth weight, NICU residence, or family history (Berlin, Bordelon, St John, Wilensky, Hurley, Kluka, Hood, 1998) (as cited in Dolphin, 2004, doctoral theses).

Numerous researchers' report (Raj, Gupta & Anand, 1991; Berlin, Morlet and Hood, 2003) also cautions clinicians that infants with risk factors have reversible features of auditory dys-synchrony. Thus, it becomes all the more important for us to be able to differentiate such conditions (AMD) from AD, which is most often irreversible. But it is difficult to identify the exact nature and type of hearing loss in infants and toddlers with risk factors using routine audiometric procedures as they present with overlapping features on routine audiological tests (ABR, BOA, OAE and Immittance) in a single assessment. So an appropriate test battery becomes essential in order to differentiate these mimicking conditions.

McPherson et al. (1989) reported that a fragment of LLR or complete LLR can be obtained in infants even at birth. However, most of the studies using LLR have been

carried out in adults and there is very little literature (some mentioned above) about LLR in infants to identify AD. Though the literature on AD in adults suggests that it may not be sensitive to identify AD, as it is not present in all the adults with AD, still it might be a sensitive tool for infants to identify such conditions. It may be recalled that during the neural development dendritic arborization and synaptogenesis occur. Due to auditory deprivation the synapses lose their function or die which might have lead to absence of LLR in most of the adult cases with AD. However, it is likely that if LLR is administered during synaptogenesis one might observe LLR in most of the infants.

Lee, McPherson, Yuen and Wong (2001) reported of two cases (school going children) with AD, one with absent MLR and present LLR while the other had presence of both MLR and LLR (N1/P2). Thus, LLR could be useful tool to identify and differentiate different conditions in children with risk factors, if not all, at least most of the cases.

Coles and Mason (1984) have used LLR for threshold estimation using tone bursts and they report of discrepancy of as much as 7.5 dB for average of 500 Hz, 1 KHz and 2 KHz frequencies between the subjective and objective (LLR) threshold. ABR-based protocol (use of click rather than tone bursts) can be used for difficult to test population and test can be administered under sedation (Hyde, 1997). He suggested that 15 dB considerations should be taken while plotting the behavioral thresholds if tone burst is used. Thus, the use of LLR might help us not only to solve this paradox (AMD Vs AD) but also help in establishing appropriate behavioral thresholds at least with some degree of accuracy.

Aim of the study:

Thus the study was taken up with the aim to:

1. Check the importance of LLR in pediatric hearing assessment, especially to differentiate AMD from AD and permanent hearing impairment.
2. Establish the normative data for ABR and LLR in infants of 1.5 years and 2 years respectively.

REVIEW OF LITERATURE

Problems in Pediatric Hearing Assessment:

Pediatric Population is a diverse group in terms of the auditory behavior. A number of factors may influence the testing and the interpretation of the results in infants and young children, thus making it more difficult and placing more demands on the Clinician in terms of skills for testing and interpretation of the obtained results.

High Risk Register (HRR) was developed to identify infants who, because of family histories or pre and perinatal birth complications were considered at risk for hearing loss. The performance of HRR has evaluated by Turner (1990) who completed a detailed analysis of each factor. According to these investigators, while the cost of HRR for screening had a lower cost compared to other methods, its hit rate was selectively poor (<60%). They also concluded that despite its low cost, the HRR misses significant number of infants with hearing loss. Mahoney and Eichwald (1979) reported the sensitivity and specificity of HRR as 65% and 75% respectively.

Infants and very young children are difficult to test in terms of obtaining frequency specific behavioral audiometric thresholds. Neonates and infants are a bundle of reflexes in their first few months of life. Most of the responses to acoustic stimulation in them would be reflexive in nature (cited in Northern and Downs, 2002) and hence, the assessment needs to be done by recognizing these reflexes which would induce more chances of errors and reduce the reliability of the results.

Maturation of the auditory system and hence the associated behavior may show high degree of variability- occurring rapidly in some children and rather slowly in others. Depending upon the stage of maturation both the subjective tests (BOA, VRA,

etc.) and the objective tests (ABR, MLR, LLR, etc.) would show variations in results. In terms of behavioral testing (BOA), infants and neonates show a localizing response only after the age of 4 months (cited in Northern and Downs, 2002). So, expecting such kind of a response before this age would lead to erroneous results. Similarly, the ABR peaks (III, V) continue to mature till 2-3 years of age (Salamy, Mendelson, Tooley, & Chaplin, 1980; Cox, 1985) and also the interpeak latencies gradually reduce to adult values by this age (Salamy, 1984). Sininger and Abdala (1996) reported that ABR thresholds of the neonates are elevated relative to the adult thresholds by 5-25 dB. This elevation in threshold is more at high frequencies compared to low frequencies. They attributed this finding to lesser degree of maturation for the high frequency fibers. Auditory brainstem response (ABR) latencies in normal young and very young subjects are longer than in mature subjects (Issa and Ross, 1995). Use of adult norms in the assessment of young subjects may therefore result in the erroneous reporting of abnormalities in subjects who is in no way impaired. The variability in the measurements of the children is greater than that of the adults. So the interpretation would have to be made accordingly (Issa & Ross, 1995).

In case of pediatric hearing assessment, no one test can give absolute result. A test battery is always required to arrive at the conclusion about the status of their hearing. Jerger and Hayes (1976) advocate use of cross-check principle according to which the results of a behavioral test has to be cross-checked using another physiological test before arriving at diagnosis of the condition in infants and neonates. This would yield appropriate results but at the same time would be time consuming.

Methods of assessing maturation:

Subjective method:

As cited in Northern and Downs, 2002, the infants and neonates between the ages of 4 and 16 months undergo an orderly maturation and development of predictable auditory response behavior. These responses are easily observable and can be elicited with soft acoustic signals. A normal hearing alert infant will respond in the predictable manner in accordance with his/her mental age. Infact, the kind of responses one looks for are very age-specific, depending on the maturation of the infant. This has been shown in Figure 1.

All normal-hearing infants and babies younger than 36 months show an easily observable startle response to a sudden onset stimulus of 65 dBSPL or louder.

Birth to 4 months:

At this early age, auditory responses are limited and largely reflexive. In a very quiet environment one may see an eye-blink or eye-widening response to soft sounds from noise-makers or other subtle auditory signals. The only reliable auditory response is the Moro startle response or the "surprise" eye-blink to louder sounds. At 3-4 months of age, the infants may begin to show a slow head turn towards a sound.

4-7 months:

By 4 months the infant begins to turn his/her head towards the sound source in a more consistent, but still wobbly, manner. By 7 months, the infant's neck muscles will be strong enough to permit a direct turn towards the side from which the sound is presented. The head turn may not be a direct localization to a sound presented at a

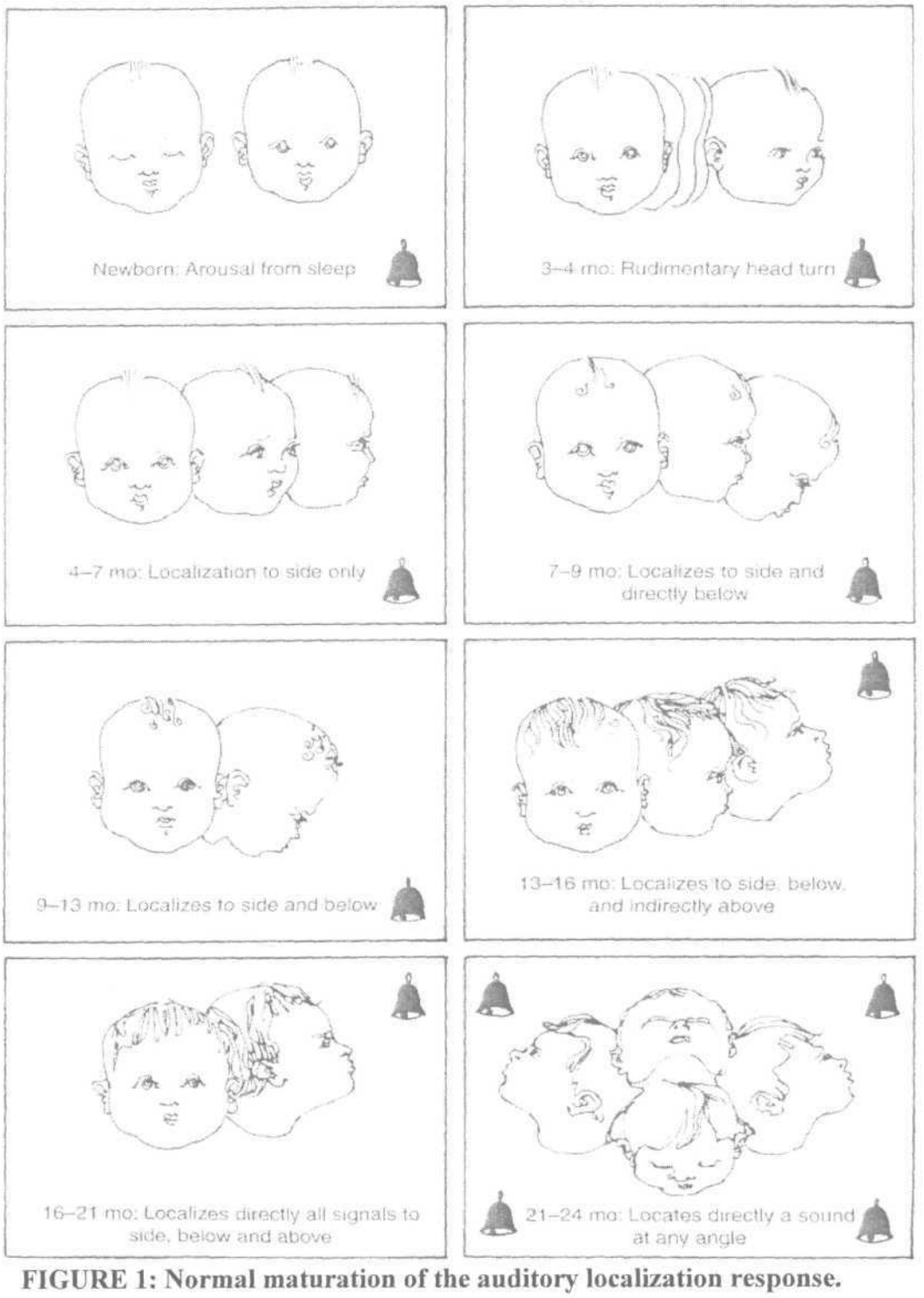


FIGURE 1: Normal maturation of the auditory localization response.

lower level beneath the eyes. For this preliminary response the infants turns towards the side but only in a lateral plane.

7-9 months:

Between 7-9 months the infant begins to identify the precise location of the sound source with a direct head turn. By this age the localization response is brisk and firm. However, it is likely that the infant will not yet look directly at a sound on a higher plane (i.e., above the eye level).

9-13 month:

By the end of 13 months of age, the infant is able to localize sounds briskly and directly in any plane above or below eye level. By 12 months of age, the curiosity of the child is full blown and quick localization to an appropriately presented auditory stimulus will be noted by children with bilaterally normal hearing. By this age, full maturation of the child's auditory development has been attained.

Age	Noise-makers (Approxim-ate dBSPL)	Warble pure tones	Speech (dBHL)	Expected Response	Startle to speech (dBHL)
0-6 weeks	50-70	75	40-60	Eye-widening, eye-blink, stirring or arousal from sleep, startle	65
6weeks-4 months	50-60	70	45	Eye-widening, eye-shift, eye-blink, quieting; beginning rudimentary head-turn by 4 months	65
4-7months	40-50	50	20	Head-turn on lateral plane towards sound; listening attitude	65

7-9months	30-40	45	15	Direct localization of sounds to side, indirectly below ear level	65
-13months	25-35	38	10	Direct localization of sounds to side, directly below ear level, indirectly above ear level	65
13-16months5	25-30	30	5	Direct localization of sound on side, above and below	65
16-21 months	25	25	5	Direct localization of sound on side, above and below	65
21-24months	25	25	5	Direct localization of sound on side, above and below	65

TABLE 1: Auditory Behavior Index for Infants: Stimulus level and types of Response (testing done in sound room). McConnell and Ward (1967) (as cited in Northern and Downs, 2002).

The following figures (Figure 2 and 3) show the development of auditory responses from new born to 9 months of age and from 9 months to 24 months of age (as cited in Northern and Downs, 2002).

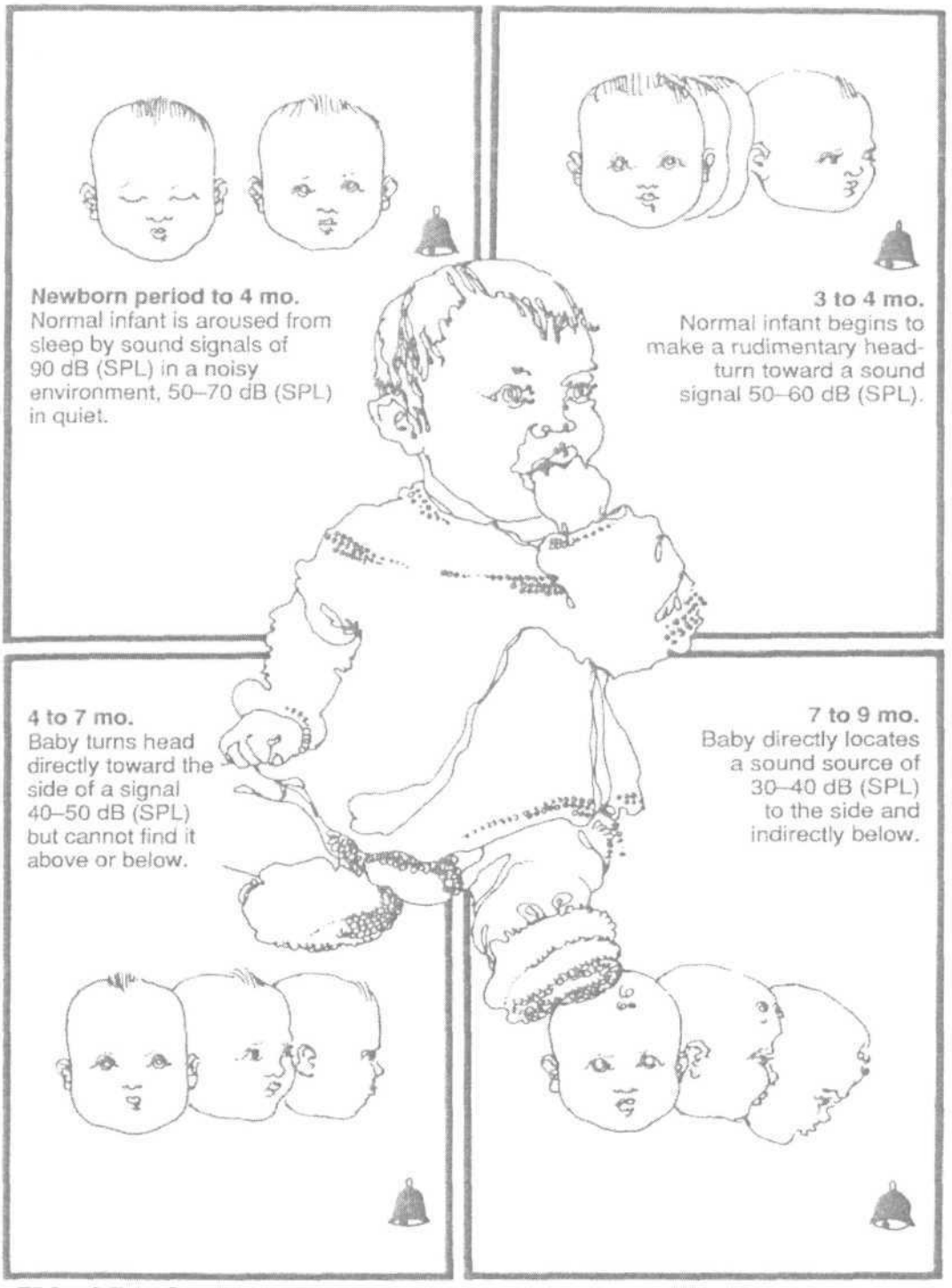


FIGURE 2: Responses from newborn to 9 months.

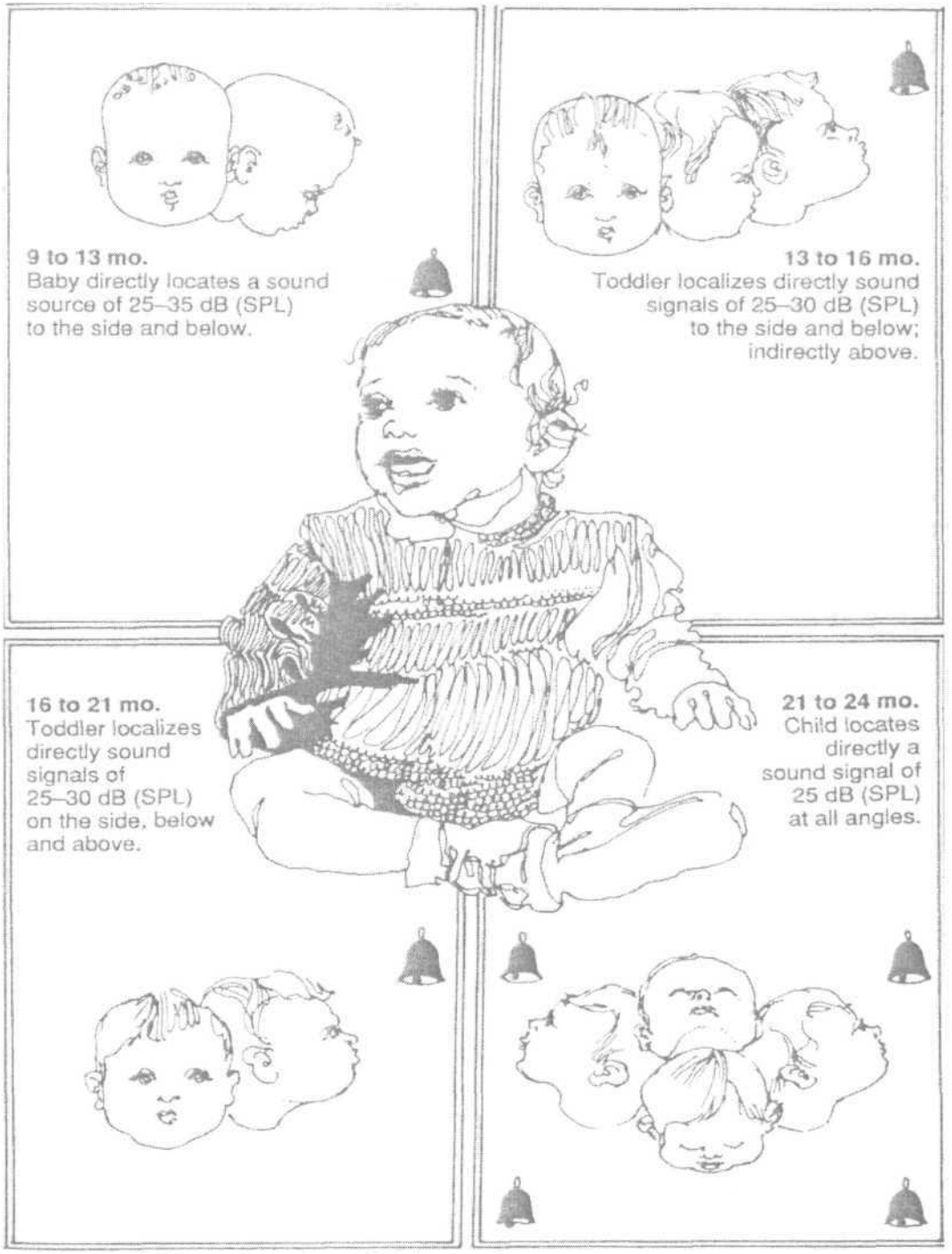


FIGURE 3: Responses from 9-24 months.

The table above is an index of auditory behavior of infants (McConnell and Ward, 1967, as cited in Northern and Downs, 2002). Thus, it is up to the audiologist to keep all this in mind before going to identify hearing impairment. However, it is essential to remember that all these behaviors are appropriate if the infant or the child is devoid of any risk factor, developmental delay or associated problems. Hence, the results obtained from this would continue to be erroneous because the amount of subjectivity involved.

Objective methods:

1. Oto-Acoustic Emission (OAE):

Changes in first week:

TEOAEs are more likely to be present and have greater amplitude on fourth day of life compared to the first day (Kok et al., 1992, 1993). The assumption is that the changes are related to the clearing of ventrix from the ear canal and fluid from the middle ear (Doyle et al., 1997).

Changes in first month:

Bonfils et al. (1992b) found that EOAEs were present in 93% of the preterm infant ears. There were no statistically significant variations in EOAE amplitude with gestational age from 32 to 41 weeks. Smurzynski et al. (1993) reported that preterm infants born at 24-33 weeks gestational age and tested at 33-43 weeks gestational age tended to have TEOAEs at 90' percentile for normal full term neonates. They speculated that the maturation of the auditory periphery followed a different time course in premature versus full-term neonates. In a longitudinal study of full-term

neonates, Widen and Norton (1993) found the overall amplitude of TEOAEs to be greater at the age of 1 month than at age of 1-2 days.

2. Immittance:

Sprague et al. (1985) tested a series of 53 normal neonates under the age of 130 hours and found that no infant had a flat tympanogram at 220 Hz. So, a flat tympanogram may be implicated in the presence of middle year pathology in the infants and neonates.

In infants, the acoustic reflexes are more likely to be present at 660 Hz than 220 Hz probe tone (McMillan, Bennett, Marchant, & Shurin, 1985; Sprague et al., 1985). In both studies, acoustic reflexes were recorded in up to 80% of the infants with 660 Hz probe, whereas acoustic reflexes were recorded in fewer than 50% of the infants with 220 Hz probe.

3. Auditory brainstem response (ABR):

ABR is actually a test of neural synchrony and is dependent upon the ability of neurons to maintain precise timing and respond synchronously to external stimuli (Jewett and Williston, 1971).

Stockyard and Westmoreland (1981) identified several limitations of ABR evaluations in the neonatal population. A heightened vulnerability of the neonatal wave potentials to certain technical and subject factors should be of concern. Stimulus intensity calibration can be a major source of variability in peak and interpeak latencies. Uncertainty about the gestational age versus conceptual age of the infants may confuse the interpretation, because of the rapid change of maturational levels-in auditory

transmission time. Between the ages of 18 months and 25 years of age, ABR shows little change in latency or amplitude, (as cited in Northern and Downs, 2002).

ABR has been considered a reliable tool to assess the maturational trends of the auditory system and this has been abundantly documented in the literature (Salamy & McKean, as cited in Salamy, Eggermont, & Elredge, 1994). Prior to 30 weeks of gestational age, a repeatable ABR may or may not be recorded, with the variability seemingly related to both intensity of the signal and the infant's general status (Starr et al., 1977). At 30 to 32 weeks gestational age, a waveform characterized by waves I, III, and V is commonly noted. By three to four months of age (52 to 56 weeks gestation), waves II and IV also emerge (Krumholz et al., 1985; Salamy, 1984).

Auditory brainstem response (ABR) latencies in normal young and very young subjects are longer than in mature subjects (Issa and Ross, 1995). The ABR peak I is matured by about 3 months of age whereas peaks (III, V) continue to mature till 2-3 years of age (Salamy et al., 1980; Cox, 1985) and also the interpeak latencies gradually reduce to adult values by this age (Salamy, 1984). Sininger and Abdala (1996) reported that ABR thresholds of neonates are elevated relative to the adult thresholds by 5-25 dB. This elevation in threshold is more at high frequencies compared to low frequencies. They attributed this finding to lesser degree of maturation for the high frequency fibers.

Several other factors are less commonly assessed but also reflect the ongoing maturation of the auditory system. The amplitude of the component waves and the resultant V/I amplitude ratio is one such measure. Contrary to the adult form in which Wave V is the largest wave, Waves I and III are equal to or slightly greater than Wave

V in the neonate. Subsequently wave V/I ratio is small. All waves increase in amplitude until approximately 2-4years of age with Wave V exhibiting the greatest growth (Cox, 1985; Salamy, 1984). The prolongation in the Ist peak latency has been reported to be ranging from 0.3 ms (Goldstein, Krumholz, Felix, Shannon, & Carr, 1979; Jacobson, Morehouse & Johnson, 1982) to over 1 ms (Cox, Hack, & Metz, 1981) in comparison to adult values

Morgan, Zimmerman, & Dubno (1987) investigated the auditory abilities using ABR of a group of 50 full term healthy newborns as well as 20 older children and adults. They observed increased latencies for Waves I, III, and V for newborns relative to the older age group. The result suggests that the neurological system is the primary source of differences between the newborns and the older age group. Hence, if ABR differences are found in normal full term healthy newborns it is not surprising that some investigators (Salamy, Eggermont, & Elredge, 1994) have found ABR abnormalities associated with specific disease states like asphyxia, apnea, intracranial hemorrhage, hyperbilirubinemia, etc.

Anand, Gupta, & Raj (1991) administered ABR on 24 newborn infants with asphyxia complicated by hypoxic-ischemic-encephalopathy (HIE). 20 normal full term infants and neonates with no apparent neurological disorder were also examined for comparison. ABR abnormalities were found with greater frequency in neonates with severe HIE (stage III) than those with stage II HIE (75% Vs 10%, $p < 0.001$). Further, ABR abnormalities wee found with stage II HIE only when duration of neurological abnormalities was greater than 5 days. There was no difference between the ABR latencies of the asphyxiated and the non-asphyxiated infants. Raj, Gupta, and Anand

(1991) recorded BAER responses from 68 at risk neonates at average post-conceptual age of 40 weeks. On re-evaluation 8 out of 13 who had failed on BAER earlier had developed normal thresholds and by 6 months follow-up, only 3% had hearing loss. Misra, Katiyar, Kapoor, Shukla, Malik, and Thakur (1996) reported the BAER abnormalities and their reversibility in neonates with birth asphyxia.

Fizhardinge and Pape (1981) (as cited in Salamy, Eggermont, & Elredge, 1994) reviewed status of 62 surviving very low birth-weight infants who had received ventilatory assistance as neonates. Clinical loss was diagnosed in 30% of those with major neurological deficit with an incidence of 12% in those without neurological deficits.

Roberts, Davis, Phon, Reichet, Sturtevant, & Marshall (1982) took 75 patients of the NICU diagnosed as having multiple risk factors like hyaline membrane disease, aminoglycoside therapy, hyperbilirubinemia, infections, and intraventricular hemorrhage. Wave V at 70 dBnHL in 50% of the infants tested at 32 weeks post-conceptual age and at 40 dBnHL in 50% of the infants tested at 40 weeks post-conceptual age was detected. 23 of those who had initially failed on the ABR were retested after 6 months and only 1 case had confirmed severe hearing loss. Thus, they concluded that ABR failures apparently resulted from immaturity.

Galambos and Galambos (1975) had studied the ABR in pre-mature infants and found that there is a drop in latency of the ABR peaks with age and this is related to maturational changes.

Roberts, Davis, Phon, Reichet, Sturtevants, and Marshall (1982) conducted ABR on 75 patients with risk factors. 23 infants who had initially failed on the ABR test were

retested after 6 months and only one case had a confirmed severe hearing loss diagnosis. Thus, they concluded that ABR failures resulted mainly from immaturity.

Using these parameters of ABR, the maturation of a particular subject can be evaluated based on comparison with the normal developmental pattern.

2. Lons Latency Potential (LLR):

The long latency auditory evoked potentials are characterized by components comprising the time domain of 50-500 ms (McPherson and Starr, 1993) and are labeled according to their polarity and latency at the vertex (Picton et al., 1978). Major components in the long latency auditory evoked potentials include a positive component at about 60 ms, another positive component at 160 ms and two negative components at 100 and 200 ms (McPherson and Starr, 1993). LLR could be recorded from both the premature and full term newborns and can be used for finding auditory sensitivity in this population (Barnet & Lodge, 1966; Rapin, Ruben & Lyttle, 1970; Taguchi, Picton, Orpin, & Goodman, 1969).

Maturation of Auditory system occurs from peripheral to central (auditory nerve to auditory cortex) (Romand, 1983; Montandon, Cao, Engel, &Grajew, 1979; Stockard & Stockard, 1981, 1983), which would implicate that LLR, should be present if ABR is present. This also receives support from Starr, Picton, Sininger, Hood and Berlin (1996) who reported presence of LLR in the subjects with Auditory Neuropathy.

LLR requires much lesser degree of synchrony of firing of the ANFs (Kraus, Bradlow, Cheatham, Cunningham, King, Koch, Nicol, McGee, Stein & Wright, 2000). The physiology behind this aspect has been reported by Kraus et al. (2000) - The cortical potentials reflect neural synchrony differently than ABR. The ABR peaks

reflect synchronous spike discharge generated in the nerve tracts, whereas the peaks in cortical responses reflect the summation of excitatory post-synaptic potentials. In other words, the ABR reflects action currents in axons, while the cortical potentials reflect slow dendritic events. Because unit contributions to the ABR are biphasic and of short duration, ABR peaks tend to cancel when discharges are separated by fractions of a millisecond. In contrast, for cortical potentials, the waves are so slow that contributions separated by several milliseconds contribute to these later waves. While the ABR reflects highly synchronous discharge with millisecond precision, the synchrony required for cortical potentials is on the order of several milliseconds.

Ohlrich et al., (1978) reported a mean reduction in P2 latency of 70-80 ms from 2 weeks to 3 years of age. The mean Nl latency reduction was reported to be only about 10 ms over the same age range. These results were also consistent with the cross-sectional study conducted by Barnet, Ohlrich, Weiss, & Shanks (1975). LLR can be used to monitor maturation in infants and neonates (Barnet, Ohlrich, Weiss, & Shanks, 1975)

Based on the results from these studies, it can be concluded that LLR can be successfully used to study the course of auditory system maturation especially at the cortical level.

Generators of LLR:

Knight, Scabini, Woods, and Clayworth (1998) suggested that the Superior Temporal Plane (STP) and Lateral Superior Temporal Gyrus (LSTG) are important to generation of the long latency auditory evoked potentials, at least out to 200 ms.

Knight, Scabini, Woods and Clayworth (1998), studying patients with lesion of the STG and Inferior Parietal Lobe (IPL), noted that the P60 and N100 (labeled as P45, N1a and N1c in their report) are generated by 'radially oriented dipoles located in the STG'.

The majority of research suggests that the P160 is generated in the 'Primary Auditory Cortex within the Sylvian Fissure contralateral to the side of stimulation' (Baumann, Rogers, Papanicolaou, and Saydjari, 1990; Makela and Hari, 1990). Baumann has suggested that wave occurring at about 160 ms demonstrates a "trend" toward differences in the dipole distribution between ipsilateral and contralateral stimulation (Baumann et al., 1990) This is somewhat different than the location suggested by Scherg, Vajsar and Picton (1989) who identified the source in the supratemporal plane near, or possibly in, the primary auditory cortex and having bilateral vertically oriented dipoles.

Simson, Vaughan, and Ritter (1977a) argued that the response at 200 ms originates from both primary auditory cortex and secondary auditory cortex. However, more recent findings would suggest that the N200 has its origins in the supratemporal cortex (Makela and Hari, 1990; Pantev, Lehnertz, and Lutkenhoner, 1988; Pellizone, Williamson, and Kaufman, 1985). These observations are very similar to the ones reported by Scherg (Scherg et al. 1990) for the PI60.

Although the Auditory Evoked Responses (AER) contains contributions from multiple temporally overlapping generators (Naatenen & Picton, 1987), generation of the P1/N1/P2 complex is dominated by activity in the auditory cortex (Elberling Bark,

Kofoed, Lebech, & Saermark, 1982; Scherg, Vasjar, & Picton, 1989; Vaughan & Arezzo, 1988; Vaughan & Ritter, 1970).

Based on the intra-cortical recordings of Liegois-Chauvel et al. (1994), the generator complex for PI has been attributed to the lateral portion of Heschl's gyrus (likely in the secondary auditory cortex) and its early-maturing cortical layers III and IV (Ponton et al., 2002). PI has been proposed to index the transient encoding of the acoustic features of sound (Ceponiene et al., 2002b). N2 is a large, dominant negativity that is seen at approximately 240-280 ms in young and school-aged children (Ceponiene et al., 2002b; Cunningham et al., 2000).

Maturation of LLR:

It has also been reported by McPherson (1989) that LLR or at least a component of LLR can be present in normal hearing infants even at birth. PI latency and amplitude change as a function of age (Ceponiene et al., 2002b; Cunningham et al., 2000; Korpilahti, 1996; Ponton et al., 2000, 2002; Sharma et al., 1997). PI is the dominant peak of the obligatory (exogenous or sensory) Event Related Potentials (ERPs) in children from early childhood (Kuushnerenko et al., 2002a). PI latency and amplitude change as a function of age (Ceponiene et al., 1996; Cunningham et al., 2000; Korpilathi, 1996; Ponton et al., 2000, 2002; Sharma et al., 1997).

Ohlrich et al., (1978) reported a mean reduction in P2 latency of 70-80 ms from 2 weeks to 3 years of age. These results were also consistent with the cross-sectional study conducted by Barnet et al., (1975), Goldstien (1973) and Polich, Howard, and Starr (1985) relate that the late potentials mature at approximately 8-10 years of age. These statements are consistent with the data on a small pediatric population (Goodin et

al., 1978). P2 latency changes from 230 to 150 ms and N2 latency from 535 to 320 ms from 15 days to 3 years of life (Barnet et al., 1975; Ohlrich et al., 1978). Ohlirich et al., (1978) reported a mean reduction in P2 latency of 70-80 ms from 2 weeks to 3 years of age. The mean reduction in latency of Nl over the first 3 years of life was reported to be comparatively less dramatic (about a 10 ms reduction) (Ohlrich et al., 1978).

Report from literature is controversial with regard to N2 potential being endogenous (O'Donnell, Shenton, McCarley, Faux, Smith, Salisbury, Nestor, Pollak, Kikinis, & Jolesz, 1992) or exogenous (Ceponiene, 2001; Naatanen, 1992; Kurzberg et al., 1986). N2 latency was reported to reduce from 535 to 320 ms from 15 days to 3 years of life (Barnet et al., 1975; Ohlrich et al., 1978)

Overall for all LLR peaks, it has been said in literature that latency decreases as a function of increasing age during childhood, up until 10 years, although the most pronounced alterations occur within the first year of life, and to a lesser extent within 2-5 years of age (Akiyama, Schulte, Schultz, & Parmalee, 1969; Ohlrich, Barnet, Weiss, 6 Shanks, 1978; Ohlrich & Barnet, 1972; Cody & Bickford, 1965, Davis & Onishi, 1969; Weitzman & Graziani, 1968; Davis, 1965).

Hyde (1997) found 10 dB discrepancy between the LLR threshold in asleep condition and the behavioral threshold (LLR threshold> Behavioral threshold), thus suggesting use of LLR as tool for threshold estimation. Coles and Mason (1984) have used LLR for threshold estimation using tone bursts and they report of discrepancy of as much as 7.5 dB for average of 500 Hz, 1 KHz and 2 KHz frequencies between the subjective and objective (LLR) threshold. ABR-based protocol (use of click rather than

tone bursts) can be used for difficult to test population and test can be administered under sedation (Hyde, 1997). He suggested that 15 dB considerations should be taken while plotting the behavioral thresholds if tone burst is used.

Keeping the above studies in mind, it would be possible to predict stage of maturation in the infant or toddler based on the LLR results.

METHOD

The present study was taken up with the aim of checking usefulness of LLR in differential diagnosis of Auditory Dys-synchrony (AD) from, its mimicking condition in terms of routine audiological test results, Auditory Maturational Delay (AMD). It was also aimed to develop the norms for LLR and ABR for infants less than 2 years and 1.5 years of age respectively.

Subjects:

60 infants/ toddlers (35 male and 25 female) were taken for the study with age below 2 years at the time of first evaluation. The subjects included both, those with risk factors which are associated with hearing impairment and also those who did not demonstrate any such risk factors. The family history of congenital or acquired hearing loss at an early age was also specifically looked for in these subjects.

Apart from this, all the subjects were also distributed in 4 groups based on their results of ABR and LLR irrespective of presence or absence of risk factors for further analysis. Group I was assigned those subjects who had both ABR and LLR present where as Group II and III consisted of those with ABR absent - LLR present and ABR present at least in second or third valuation- LLR absent in first evaluation respectively. The final group, Group IV comprised of those subjects who had neither ABR nor LLR present. The number of subjects, that formed a part of Groups I, II, III, and IV, was 18, 14, 10, and 13 respectively. These sub-groups were made to understand the importance of LLR in pediatric hearing assessment.

For developing the normative data, only those subjects were considered who did not demonstrate any risk factor associated with hearing loss. For ABR, there were two

groups- within 6 months (Group A) and above 6 months (Group B) of age.Group A comprised of 14 subjects (28 ears) whereas Group B consisted of 13 subjects (26 ears). For LLR, the subjects were divided into 4 groups- upto 6 months (Group a), 7-12 months (Group b), 13-18 months (Group c), and 19-24 months (Group d). The subjects who turned up for re-evaluations were also considered in the group division more than once depending upon the age at that time.

Instrumentation:

1.) A calibrated two-channel diagnostic audiometer OB922, with impedance matched speakers, was used to obtain behavioral responses (BOA).

2.) Transient Evoked Oto-Acoustic Emissions (TEOAE) were acquired using ILO292 (software version 5) in full TE menu option, in order to examine the status of the outer hair cells to rule out absence or abnormal Auditory Brainstem Responses (ABR) due cochlear pathology.

3.) Intelligent Hearing System (HIS) Smart EP version 3.86USBeZ was used to obtain Auditory Brainstem Responses (ABR) and Long Latency Potentials (LLR) for checking the integrity of neural pathway at the levels of brainstem and cortex respectively.

4.) An immittancemeter, Grason Stadler Inc. (GSI) Tympstar, was used to rule out the presence of middle ear pathology causing absence of TEOAE or prolongation of ABR wave latencies.

All the instruments were checked for calibration prior to use on each of the subjects according to manufacturer's recommendations.

Test Environment:

All the tests were carried out in a well illuminated air conditioned (AC) room which was also acoustically treated with noise levels within the permissible limits as recommended by ANSI (1991) (as cited in Silman & Silverman,).

Test Procedure:

Case History:

Detailed information regarding the history of prenatal, natal and postnatal medical conditions was secured for each of the subjects. Medical records were looked for to obtain information regarding risk factors pertaining to congenital or early onset hearing loss like TORCH infections, neonatal jaundice, birth asphyxia, low APGAR scores, seizures, premature delivery, low birth weight, drinking of Amniotic fluid at the time of delivery, Mother getting Chicken Pox in the first trimester of pregnancy, and Bronchopneumonia. A detailed report regarding the auditory behavior of the subject at home for various environmental sounds like call bell, dog bark, voices from TV or radio, pressure cooker whistle etc. was obtained from the parents or caretakers. Parents were counseled regarding frequent follow-ups and were asked to look for changes in the auditory behavior and also to report those changes during the next follow-up visit.

Test Battery;

1.) Behavioral Observation Audiometry (BOA):

Behavioral responses of the subjects were obtained in sound-field condition using warble tones or narrow band noise of 500 Hz, 1 KHz, 2 KHz, and 4 KHz and also speech stimuli. It was carried out in a double-room situation. The subjects were seated

on the caretakers lap at a distance of 1 meter from the speakers and at an azimuth of 45° in the observation room. The stimuli were presented sequentially and the starting level was decided based on the parental report about the auditory behavior at home. The lowest levels of presentation of each of the stimuli, at which the subject exhibited some sort of auditory behavior, was noted down.

*2.) **ABR** and **LLR:***

Single channel ABR and LLR were recorded in asleep condition using IHS Smart EP instrument. The electrodes were placed at Fz (high forehead) for Non-inverting (positive), Al (left ear mastoid) for inverting or ground and A2 (right ear mastoid) for ground or inverting. Neo-prep was used for preparing skin at these electrode sites in order to obtain allowable impedance values. Independent at each site and inter-electrode impedances were maintained within 5 KD. TDH-39 headphones were placed taking care not to dislodge the electrodes from their positions and the electrode impedances were re-measured to make sure that the impedance stayed within the desired levels at each of the electrodes. The parameters used for ABR and LLR recording have been shown in Table 2 and 3 respectively.

Acquisition Parameter	Stimulus Parameters
Sensitivity- 50 μV Band-pass Filters- Low Pass- 3 KHz High Pass- 30 Hz Notch Filter- Off Artifact Rejection- On Electrode Montage- Al-Fz-A2 Time Window- 15 msec.	Type of stimulus- Click Polarity- Rarefaction Intensity- Variable Number of stimuli- 1500 Repetition rate- 1 l.l/sec. (to obtain better waveform morphology)

TABLE 2: Parameters used to acquire ABR.

Amplifier Set-up	Stimulus Parameters
Sensitivity- 50 μV Band-pass Filters- Low Pass- 300 KHz High Pass- 1 Hz Notch Filter- Off Artifact Rejection- On Electrode Montage- Al-Fz-A2 Time Window- 750 msec.	Type of stimulus- Click Polarity- Rarefaction Intensity- 70 dB Number of stimuli- 300 Repetition rate- 1.1/sec.

TABLE 3: Parameters used to acquire LLR.

Presence of ABR (wave I or V) at lowest level was taken as threshold and used for interpretation as wave I is likely to be more prominent in infants. In case of LLR, the latencies of the two positive peaks (P1 and P2) and the two negative peaks (N1 and N2) were noted, whenever these were present. In case, any one or more of these peaks were absent, only the latencies of the peaks that were present were noted. LLR responses were shown to three experienced Audiologists to identify the peaks.

Infants with presence of ABR at 30 dBnHL and also presence of LLR were not followed-up. Only those infants who demonstrated absence of one or both of these potentials in the first evaluation were asked to follow-up to monitor any changes with development and diagnosis.

3.) Oto-Acoustic Emissions (OAE):

TEOAEs were obtained using ILO292 instrument with a foam tip positioned in the external auditory canal so as to give a flat frequency spectrum across the frequency range. The stimuli were clicks filtered with a band-pass filter encompassing 500 to 6000 Hz. The duration of the rectangular pulses (clicks) was 80 μsec. The level was

maintained at 80 dBpkSPL in the external auditory canal and the inter-stimulus interval was kept constant at 20 msec. A total of 260 averages above the automatic noise rejection level of instrument were stored for analysis. The presentation mode included a series of four stimuli, three at same level and of same polarity and the fourth of three times the level of the either of the three and opposite in polarity. This, called the non-linear averaging, is used for artifact reduction during the response acquisition. The responses were considered as emissions based on the reproducibility and the signal-to-noise ratio (SNR). The overall SNR of greater than or equal to +3 dB and the reproducibility of greater than 50% were considered (Dijk and Wit, 1987) for it to be considered as a presence of an echo or emission.

4.) ***Immittance:***

Tympanometric measurements were done using 678 Hz probe tone (since infants and toddlers have mass dominant middle ear system) or 226 Hz based on the age of the subject at the time of evaluation. This was done to rule out absence of OAE due to middle ear pathology. Appropriate probe tips were used to obtain hermetic seal and comfortable pressure for the subject. The parameters documented were types of tympanogram to go with ear canal volume, acoustic admittance and the tympanometric peak pressure. The results were also correlated with the ENT findings.

Analysis:

All the subjects were also distributed in 4 groups based on their results of ABR and LLR for further analysis for the purpose of differential diagnosis between those with normal hearing, with AD or AMD and with permanent hearing loss. An account of the group divisions has been summarized in Table 4.

GROUP	CRITERIA
Group I	ABR present - LLR present
Group II	ABR absent - LLR present
Group III	ABR present - LLR absent
Group IV	ABR absent - LLR absent

TABLE 4: Criteria for group division.

For developing the normative data of ABR and LLR, data from the subjects without any risk factors were used and those with any semblance of a risk factor were discarded for this purpose.

RESULT AND DISCUSSION

The present study was aimed at checking the usefulness of LLR in pediatric hearing assessment and developing the normative data for ABR and LLR for infants and toddlers of less than 1.5 years and less than 2 years of age respectively.

The subjects were divided into four groups based on the presence or absence of ABR and LLR irrespective of the presence or absence of risk factors to understand the role of LLR in pediatric hearing assessment. Group I consisted of 18 subjects, Group II of 14, Group III of 10 and Group IV of 13 subjects. Tables 5, 6, 7, and 8 show the audiological profile of the individual cases classified under these different groups. The profile includes findings of different tests (BOA, OAE, Immittance, ABR, and LLR) that were administered on each of the subjects who participated in the study. Table 5 shows the audiological profile of cases who demonstrated presence of both- ABR and LLR (Group I) where as Tables 6 and 7 show the profiles of those with ABR absent - LLR present Group II) and ABR present in at least second or third evaluation - LLR absent in first evaluation (Group III) respectively. Table 8 shows the audiological profiles of those subjects who had neither of the two (ABR and LLR) present (Group IV).

Sub	Risk Factors	BOA Level **(dBHL)**		Tympanogram Type		OAE		**ABR** Threshold **(dBnHL)**		**LLR** at 70 **dBnHL**	
		T	S	R	L	R	L	R	L	R	L
1	P	40-55	35	A	A	P	P	30	30	P	P
2	P	45-50	40	A	A	P	P	30	30	P	P
3	Ab	35-50	35	A	A	P	P	30	30	P	P
4	P	50-65	50	B	B	Ab	Ab	50	40	P	P
5	Ab	40-55	40	As	As	Ab	Ab	40	40	P	P
6	Ab	40-55	40	A	A	P	P	30	30	P	P
7	Ab	45-50	45	A	A	P	P	40	40	P	P
8	Ab	35-45	30	As	As	P	P	30	30	P	P
9	P	50-60	45	B	B	Ab	Ab	50	50	P	P
10	P	50-55	40	A	A	P	P	30	30	P	P
11	Ab	35-45	35	A	A	P	P	30	30	P	P
12	Ab	30-45	30	A	A	P	P	40	40	P	P
13	Ab	30-40	35	A	A	P	P	30	30	P	P
14	Ab	45-55	45	A	A	P	P	50	50	P	P
15	Ab	35-40	30	A	A	P	P	30	30	P	P
16	Ab	35-40	30	A	A	P	P	35	40	P	P
17	Ab	35-40	30	A	A	P	P	30	30	P	P
18	Ab	30-40	30	A	A	P	P	30	30	P	P

TABLE 5: Group I- Audiological Profile of subjects with ABR and LLR present (Group I). 'P' indicates 'present' and 'Ab' indicates 'absent'. 'T' and 'S' indicate 'tone' and 'speech' and 'R' and 'L' indicate 'right' and 'left' ears respectively. Similar abbreviations are used in tables 6, 7, and 8 also.

It can be seen in table 5 that subjects 1,2,4,9 and 10 had positive history for risk factors that are associated with hearing loss. Subjects 1, 2, 4, and 10 had history of Neonatal Jaundice (NJ) that did not require blood transfusion. In addition to NJ, subject 2 also reported of delayed birth cry by 1 minute, Neonatal Meningitis (NM), and Febrile Seizures at the age of 2 months. Subject 9 had history of delayed birth cry by 1 minute without any other associated complications. In spite of presence of risk factor/factors that have been found to be associated with hearing loss in literature, these subjects' audiological results fall well within normal limits for BOA, OAE, ABR, Immittance, and LLR except for subjects 4 and 9, who showed absence of OAE and slightly elevated BOA values for FM tones and speech stimuli. Occurrence of conductive pathology, as indicated by B-type Tympanogram and positive history of ear discharge, might have resulted in abnormal OAE and BOA results in these two subjects. This group was considered to have normal hearing based on the test battery result except for subject 4 and 9 as they had conductive component. The youngest age of the subject in whom LLR could be recorded was 16 days and all the components of LLR (PI, Nl, P2, and N2) were found to be present in this subject. It has also been reported by McPherson (1989) that LLR or at least a component of LLR can be present in normal hearing infants even at birth. Though all the components of LLR could be recorded in the subject 12, it is not always necessary that all the LLR components would be observable at birth. But there is high possibility of presence of at least one of the LLR components at high intensity if the infants follow normal developmental pattern. Thus, it suggested that LLR might be able to substitute ABR provided the normative data is established for this population and also the relationship between the

behavioral and LLR threshold is established. Some time LLR might be a better tool for assessing hearing sensitivity when there is mild degree of dys-synchrony which might lead to noisy ABR morphology but might show better LLR responses. This might help to identify hearing sensitivity in such cases.

Sub	Risk Factors	BOA Level						Tym lanogram Type						OAE						ABR Threshold						LLR					
		I		11		III		I		II		III		I		II		III		I		II		111		I		II		III	
		T	S	T	S	T	S	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1*	Ab	Ab	Ab	Ab	Ab	Ab	Ab	A	A	A	A	A	A	P	P	P	P	P	P	Ab	Ab	Ab	Ab	Ab	Ab	P	P	P	P	P	P
2*	Ab	35-45	35	40-45	40	40-50	40	A	A	A	A	A	A	P	P	P	P	P	P	Ab	Ab	Ab	Ab	Ab	Ab	P	P	P	P	P	P
3	Ab	NR	85-90	NR	85			As	As	B	As			Ab	Ab	Ab	Ab			Ab	Ab	Ab	Ab			P	P	P	P		
4	P	45-50	40					A	A					P	P					Ab	Ab					P	P				
5	Ab	55-65	60					As	B					Ab	Ab					Ab	Ab					P	P				
6	P	45-50	40					B	B					Ab	Ab					Ab	Ab					P	P				
7	P	35-60	40					A	A					P	P					Ab	Ab					P	P				
8*	P	65-70	65	65-70	65	65-70	65	As	As	As	As	As	As	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	P	P	P	P	P	P
9	Ab	40-55	35					As	As					Ab	Ab					Ab	Ab					P	P				
10	P	45-55	45					A	A					P	P					90	90					P	P				
11	Ab	35-45	35	30-40	35			A	A	A	A			P	P	P	P			Ab	Ab	Ab	Ab			P	P	P	P		
12	P	50-60	40					A	A					P	P					Ab	Ab					P	P				
13*	P	35-40	40	35-50	40	35-45	40	A	A	A	A	A	A	P	P	P	P	P	p	Ab	Ab	Ab	Ab	Ab	Ab	P	P	P	P	P	P
14*	P	30	30	35	35	35-	35	A	A	A	A	A	A	P	P	P	P	P	p	Ab	Ab	Ab	Ab	Ab	Ab	P	P	P	P	P	P

TABLE 6: Group II- Audiological Profile of subjects with Absent ABR but Present LLR (Group II). 'P' indicates 'present' and 'Ab' indicates 'absent'. I, 'II, and 'III' indicate the number of audiological evaluation. Similar abbreviations are also used in tables 7 and 8.

Table 6 shows the audiological profiles of subjects that were put in Group II based on ABR and LLR results (ABR absent- LLR present). This table highlights 5 subjects who had undergone three evaluations each at a interval of 3 months or more between two follow-ups and also 2 subjects who underwent two evaluations apiece at interval of three months or more. Rest of the 7 subjects underwent only 1 evaluation each. This group showed interesting finding of absence of ABR peaks even at 90 dBnHL in spite of BOA showing normal hearing in most of the subjects to severe hearing loss in subjects 1 and 3. However, all the subjects showed A-type tympanogram in presence of recordable TEOAE and presence of LLR at 70 dBnHL. Considering that the maturation of Auditory system occurs from peripheral to central (auditory nerve to auditory cortex) (Romand, 1983; Montandon, Cao, Engel, &Grajew, 1979; Stockard & Stockard, 1981, 1983), ABR also should have been present if LLR were to be present. But this was not to be in these subjects, which gives an indication towards some permanent abnormality at the level of Auditory Nerve and Brain-stem which contain the generators for different ABR peaks. ABR is actually a test of neural synchrony and is dependent upon the ability of neurons to maintain precise timing and respond synchronously to external stimuli (Jewett and Williston, 1971; Hood et al., 2002). So, the absence of ABR peaks could be because of dys-synchronous firing of the ANFs or in other words, Auditory Dys-synchrony (AD). LLR requires much lesser degree of synchrony of firing of the ANFs (Kraus, Bradlow, Cheatham, Cunningham, King, Koch, Nicol, McGee, Stein & Wright, 2000), which is why probably it was found to be present in these subjects. The physiology behind this aspect has been reported by Kraus et al. (2000) - The cortical potentials reflect neural synchrony differently than ABR.

The ABR peaks reflect synchronous spike discharge generated in the nerve tracts, whereas the peaks in cortical responses reflect the summation of excitatory post-synaptic potentials. In other words, the ABR reflects action currents in axons, while the cortical potentials reflect slow dendritic events. Because unit contributions to the ABR are biphasic and of short duration, ABR peaks tend to cancel when discharges are separated by fractions of a millisecond. In contrast, for cortical potentials, the waves are so slow that contributions separated by several milliseconds contribute to these later waves. While the ABR reflects highly synchronous discharge with millisecond precision, the synchrony required for cortical potentials is on the order of several milliseconds.

This highlights that after 3 evaluations in 5 subjects, it was possible to label them as having AD. In the first evaluation itself ABR was found to be absent and LLR present which prompted to diagnose the subjects as having AD. The follow-up testing was done only to confirm this status. All other subjects in the group were suspected to have AD based on similar findings in the first or first two evaluations but they could not be followed-up owing to time constraint or their inability to come for follow-up. Thus, we may be able to arrive at the diagnosis of infants or toddlers having AD after the first evaluation itself if ABR is absent but LLR present. This also receives support from Starr, Picton, Sininger, Hood and Berlin (1996) who reported presence of LLR in the subjects with Auditory Neuropathy which is more recently being called AD.

Subjects 3, 5, 6, 8, and 9 had absence of TEOAE which could be accounted by As-B, As-B, B-B, As-As, and As-As type of tympanogram respectively suggesting presence of conductive pathology in these subjects. The conductive pathology hampers

the reverse transmission of OAE through the middle ear system and thus prevents the OAE from being recorded at the level of ear canal. If LLR was not done, it would not have been possible to categorize these subjects into AD as most of the available literature on AD highlights the presence of OAE being an integral part of the test battery for its identification. Thus, it goes to show how important can LLR be in identifying AD in infants and toddlers at an early age even if OAEs are absent owing to some middle ear problem. This can implicate in early and appropriate use of intervention strategies or measure like cochlear implantation can be taken very early in life as there literature supports the usefulness of cochlear implantation in cases with AD (Shallop et al., 2001; Trautwein et al., 2000; Peterson et al., 2003 cited in Kirk, Firszt, Hood, and Holt, 2006; Miyamoto, Kirk, Renshaw, Hussain, 1999).

Also in subject 10, there is presence of ABR at 90 dBnHL only, which suggests a milder degree of dys-synchrony in the ANFs' firing. LLR was found to be present at 70 dBnHL in this subject. Hyde (1997) found 10 dB discrepancy between the LLR threshold in asleep condition and the behavioral threshold (LLR threshold> Behavioral threshold) and suggested about 10-15 dB discrepancy between ABR threshold and behavioral threshold (ABR threshold> Behavioral threshold) (cited in Hall, 1992). This implies that LLR and ABR thresholds should roughly coincide which is not what was found in subject 10. This subject showed a discrepancy of grater than or in worst case equal to 20 dB between ABR and LLR. Also, BOA responses were observed at 45-55 dB and 45 dB for FM tones and speech respectively which suggests that the subject was hearing sounds at much lower intensities than suggested by ABR finding. All this in conjunction led to this subject being put in the category of having AD (i.e., Group II).

The inclusion of this case in this group also receives support from Sininger (2002) who said that the neural response (ABR) will be poor or completely absent but will occasionally show a small wave V response (at high stimulus intensities). However, the subject did not come for follow-up to confirm the diagnosis. Since LLR requires lesser synchrony than ABR, even small amount of demyelinization might have led to its presence whereas a small amount of demyelinization of lower structures (Auditory Nerve and Brainstem) could have produced synchronous firing only at much higher level (90 dBnHL). So, this could even be classified in to AMD. But due to lack of information about further follow-ups it can only be a matter of debate whether to call it AD or AMD. So, if such kinds of cases are encountered, follow-ups are advisable to confirm the actual existing condition.

Apart from this, Group II comprised of 8 subjects out of a total of 14, who had history of risk factor/factors. These were subjects 4, 6, 7, 8, 10, 12, 13, and 14. Subjects 4, 6, 10, 12, and 13 had history of Neonatal Jaundice but only 4 and 13 required blood transfusion and phototherapy respectively. Subject 8 demonstrated multiple risk factors in terms of history of mother having Chicken Pox in the first trimester of pregnancy, consumption of Amniotic Fluid by the subject at the time of delivery, low blood sugar level at the time of birth, and febrile seizures at 1 month of age. Subject 10 also had the history of Birth Asphyxia to go with Neonatal Jaundice and subject 14 had Birth Asphyxia followed by Seizures few days later. So in all, 55.55% of the subjects clubbed under the AD group (Group II) had history of severe degree of risk factor/factors pertaining to hearing loss. Thus, it suggests that severe degree of risk factors showed-up in high chances of auditory abnormality and hence such infants and toddlers must be

considered for detailed audiological evaluation and LLR must be the part of the test battery to identify AD.

Sub	Risk Factors	BOA Level						Tympanogram Type						OAE						ABR Threshold						LLR					
		1		II		111		1		II		III		1		11		HI		I		II		III		I		II		III	
		T	S	T	S	T	S	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	P	60-70	55	50-70	50			A	A	A	A	A	A	P	P	P	P	P	P	Ab	Ab	90	80	30	30	Ab	Ab	Ab	Ab	P	P
2	Ab	35-50	40					A	A					P	P					40	40					Ab	Ab				
3	P	55-60	45	45-55	40			A	A	A	A			P	P	P	P			Ab	Ab	50	50			Ab	Ab	Ab	Ab		
4	Ab	45-60	40					B	B					Ab	Ab					50	50					Ab	Ab				
5	Ab	70-75	60					A	A					P	P					30	30					Ab	Ab				
6	Ab	75-80	75	65-70	60			B	B	B	B			Ab	Ab	Ab	Ab			Ab	Ab	70	60			Ab	Ab	Ab	Ab		
7	Ab	55-65	45					A	A					P	P					30	30					Ab	Ab				
8	P	65-70	65	65-70	60	55-60	45	A	A	A	A	A	A	P	P	P	p	P	P	Ab	Ab	30	30	30	30	Ab	Ab	Ab	Ab	P	P
9	P	60-65	45	40-45	40-45	30-35	30	A	A	A	A	A	A	P	P	P	p	P	P	Ab	Ab	40	30	30	30	Ab	Ab	P	P	P	P
10	Ab	35-45	35	35-40	30			A	A	A	A			P	P	P	p			Ab	Ab	40	50			Ab	Ab	P	P		

TABLE 7: Group III- Audiological Profile of subjects with present ABR and absent LLR in first evaluation (Group III).

Table 7 describes the audiological profile of subjects who were considered in Group 111 based on ABR and LLR findings. This group consisted of 10 subjects, 4 of whom had history of one or more risk factors that have been suggested to cause hearing loss. Subject 1 and 3 had history of Neonatal Jaundice to go with Seizures in early infancy where as subject 9 had history of premature delivery. Subject 8 was confronted with multiple risk factors that included Birth Asphyxia, low APGAR scores, Bronchopneumonia, and Seizures.

Six (1, 3, 6, 8, 9, and 10) out of the total of 10 subjects of this group showed presence of OAE in absence of any recognizable ABR peak even at 90 dBnHL in first recording. Based on the reports in literature, that talk of absence of ABR in presence of OAE being the feature of AD (Starr et al., 1996; Hall, 2000), these subjects could have been diagnosed as having AD. But follow-up test results in these subjects (second follow-up for subjects 3, 6 and 10 and second and third follow-ups for subjects 1, 8, and 9) suggested other wise. These follow-up recordings demonstrated presence of ABR and gradual progression towards normalcy in terms of peak latencies in those with two or three evaluations. These recordings also showed absence of LLR in presence of ABR in first recording itself, which is a big indicator that the maturation has not fully occurred at the central level (at the level of cortex). The routine audiological testing (which includes BOA, ABR, OAE and immittance), in such cases, give the findings that are similar to the findings in cases with AD (i.e., absent ABR, near normal or slightly elevated BOA, A-type tympanogram, and present TEOAE) at least in first evaluation. This can lead to a case being misdiagnosed as AD though it could be a case of delayed maturation (Auditory Maturational Delay or AMD). Comparison of the

profiles of subjects in Table 6 and 7 can give a valuable introspection in this regard. The presence of LLR in absence of ABR gives an indication towards normal cortical functioning in lieu of sub-normal or abnormal peripheral (Auditory Nerve and Brain-stem) functioning. Based on the earlier discussion with regard to table 6, the label of AD (based on peripheral-to-central course of maturation) can safely be put forth for such cases. Absence of LLR, when ABR is present (normal or abnormal) or when it is absent, shows a trend towards either AMD or severe hearing loss. But, it would be better if cases with such findings are monitored with regard to the changes in auditory behavior at home and also through regular follow-ups (preferably at 3 months intervals) till a clearer picture of the condition evolves (preferably up to 2 to 3 years of age), more so if OAEs are absent.

In subjects 4 and 6 again, the absence of OAE can be accounted by B type tympanogram in both ears of both the subjects. These have been considered in this group based on the BOA findings which suggests near normal responses to FM tones and speech in subject 4 and shows a maturational course, indicated by improvement in response levels in second evaluation, in subject 6.

So, if ABR is present at any level and LLR is absent in the first evaluation itself the case can be diagnosed as AMD if OAEs are found to be present. This receives support from the findings of 4 out of 6 subjects in table 3. These subjects (1 and 8 in third evaluation and 9 and 10 in second evaluation itself) showed the presence of LLR and also improvement in the ABR peak latencies with increase in age, thus, supporting the diagnosis of AMD which was established based on absence of LLR in the first recording session itself.

Rest of the subjects (2, 4, 5, and 7) had undergone only one evaluation. They had presence of ABR and OAE, except subject 4 (absent OAE), but LLR was absent. Absence of OAE could be accounted based on the tympanometry result which showed B-type tympanogram in subject 4. Presence of ABR and absence of LLR helped in the diagnosis of AMD in these subjects. However, follow-up is required to confirm this diagnosis.

It has been seen that absence of ABR in the first evaluation could be misleading as there can be case of delay in maturation that lead to this phenomenon. This paradox can easily be solved by the inclusion of LLR in the test battery for the hearing assessment in infants and toddlers. Thus, it is strongly recommended to include LLR in the protocol for assessing hearing in infants and toddlers.

Table 8 comprises of subjects who were put together in Group IV (ABR absent-LLR absent). 3 out of a total of 13 subjects (23.08%) had history of one or more risk factors pertaining to hearing loss. Subject 1 had history of Neonatal Jaundice, subject 13 had birth asphyxia and subject 8 had a cluster of risk factors that included prenatal high blood pressure (at 7^{th} month), premature delivery and low birth weight. All the subjects had BOA responses at much higher levels than normal hearing infants which correlated well with the findings that included absence of OAE, A-type tympanogram (except subjects 1, 2, and 9 in first recording and subjects 1 and 7 in second recording in both and left ear respectively), and no repeatable peaks in ABR and LLR recordings. Absence of LLR along with absence of OAE and ABR gives a fair indication towards subjects having permanent hearing loss. A conductive component in subjects 1, 2, 7 and 9 can not account for absence of ABR at 90 dBnHL and that of LLR at 70 dBnHL. Thus, this group of subjects can be diagnosed as having permanent hearing loss.

The differentiation between the two- AMD Vs severe hearing loss can be easily accomplished based on TEOAE findings. If the TEOAEs are present, it shows that the course of maturation may be slightly prolonged or delayed causing abnormality in ABR and LLR findings where as absence of TEOAE would indicate abnormality at the level of cochlea too, and hence severe hearing loss could be a better recommendation.

A glance at the profiles included in all the above mentioned four tables would show the importance of LLR in differential diagnosis of different conditions that are likely to be encountered when dealing with the evaluation of pediatric population of less than 2 years of age. Apart from the use of regular test battery that includes BOA,

ABR, Immittance, and OAE, the inclusion of LLR can be of real help. The following table highlights the results of different tests and the diagnosis based on it:

	BOA	Immittance	OAE	ABR	LLR	Diagnosis
1.	Normal	A-type	Present	Present	Present	Normal hearing
2.	Normal	A-type	Present	Absent	Present	AD
3.	Normal	A-type	Present	Absent/ Abnormal/ Present	Absent	AMD
4.	Abnormal	A-type	Absent	Absent	Absent	Severe hearing loss

TABLE 9: Different test results and diagnosis based on them.

As can be seen from the above table (Table 9), conditions 2 and 3 are identical if LLR results are taken away and ABR is absent in both. The Audiologist will find it very difficult to diagnose the condition or at least has to wait until the maturation has fully occurred to diagnose the condition. This difficulty can be overcome when LLR results are included. The absence of LLR can be considered for the diagnosis of AMD where as its presence can be termed as AD (based on the pattern of maturation which suggests peripheral to central course for it) based on presence of ABR at any level and absence of ABR even at high levels respectively. Thus, LLR can prove to be of immense importance in differential diagnosis of AD and AMD. Also, in first condition, though other tests indicate towards the hearing sensitivity being normal, still there may be a case of delayed maturation at higher centers (Auditory Cortex). This can be ruled out by presence of LLR. Not only that, LLR can also be used as a substitute for ABR to obtain threshold especially if ABR morphology is poor or if ABR is completely absent

as in cases with AD. And in the last condition as shown in the table, LLR can be used as supporting tool for the diagnosis of severe hearing loss. Absence of LLR would indicate minimum or no signal reaching the Auditory Cortex that can evoke a cortical response. Another possibility is that, in cases of AD, the clinician may not actually predict the exact hearing threshold of the infant as ABR is absent. Thus, LLR can be readily used for pediatric hearing assessment to differentially diagnose different conditions as well as for threshold estimation in an, other wise, unlikely scenario.

Apart from the differential diagnosis of these different conditions in pediatric population, an attempt was also made to develop normative data for ABR for infants and toddlers of less than 1.5 years of age and also for LLR peaks for infants and toddlers of less than 2 years of age in the present study. For this purpose, those subjects, who showed nonnal hearing but were associated with one or more risk factors, were not considered.

For developing the normative data for ABR peaks, subjects were divided into two groups based on age- Group A and Group B. Table 10 gives the mean, standard deviation (S.D.) and range of Ist, IIIrd and Vth peak of ABR at 90, 70, 50 and 30 dBnHL for both the groups.

Intensity	Age	Wave I				Wave III				WaveV			
		Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
90	within 6months	2.19 (N=6)	0.12	1.95	2.30	3.47 (N=6)	0.37	3.00	3.90	6.50 (N=10)	0.82	5.30	7.90
	above 6months	1.76 (N=6)	0.12	1.70	2.10	3.30 (N=9)	0.41	2.80	4.00	6.08 (N=6)	0.21	5.80	6.3
70	within 6months	3.40 (N=4)	0.14	3.30	3.50	4.97 (N=6)	0.67	4.30	5.60	7.0 (N=8)	1.3	5.50	8.60
	above 6months	2.67 (N=4)	0.46	2.10	3.10	4.35 (N=6)	0.74	3.80	5.40	6.40 (N=ll)	0.85	5.30	7.90
50	within 6months	3.40 (N=4)	0.08	3.30	3.50	5.31 (N=6)	0.61	4.80	6.20	7.74 (N=ll)	1.39	6.20	9.70
	above 6months	3.22 (N=4)	0.22	3.00	3.50	4.80 (N=6)	0.74	4.60	5.20	7.00 (N=6)	0.99	6.20	8.0
30	within 6months	4.63 (N=6)	0.91	3.30	5.60	6.5 (N=6)	1.04	5.10	7.40	7.87 (N=12)	1.13	6.50	9.90
	above 6months	4.15 (N=6)	0.61	3.50	5.10	6.30 (N=6)	0.49	5.90	7.10	7.73 (N=13)	0.90	6.20	9.20

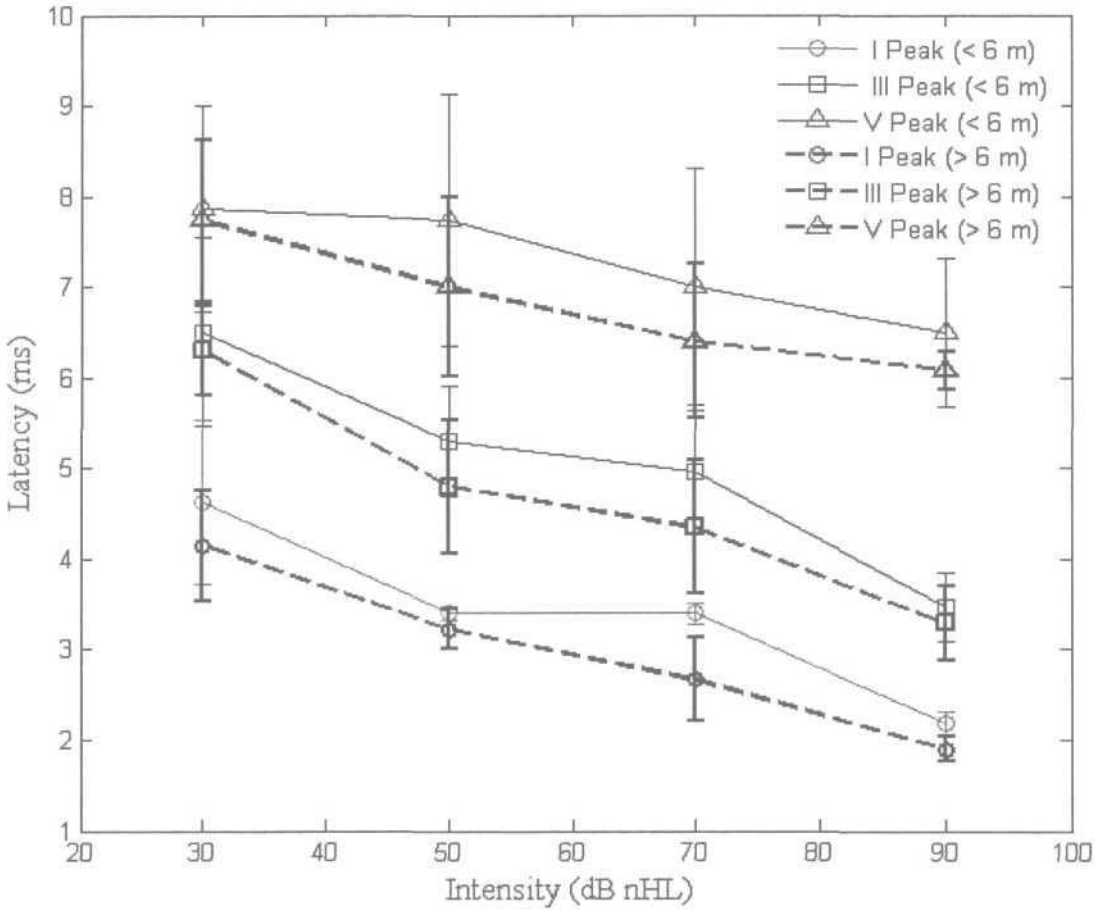
TABLE 10: The Mean, Standard Deviation (S.D.), Maximum, and Minimum latencies of ABR Wave I, III, and V at 90, 70, 50, and 30 dBnHL for two age groups (within 6 months and more than 6 months up to 18 months).

As can be seen in table 10, the latency values for all the three ABR peaks demonstrate an increase with decrease in intensity for both the age groups-Group A and Group B. It is also evident that latency decreases with increase in age for all the three peaks. In terms of the peak latencies of individual peaks, the mean differences between the 1st peak latencies of the two groups at 90, 70, 50, and 30 dBnHL are 0.43, 0.73, 0.18 and 0.48 respectively. Similarly for Illrd peak and Vth peak, these are 0.17, 0.62, 0.51, and 0.20 and 0.42, 0.60, 0.74, and 0.14 respectively. There was no consistent pattern observed for amount of reduction in latency with increase in intensity but the reduction pattern was certainly observed.

Comparison with adult values (Antonelli, Bellotto, and Grandori, 1987, cited in Hall) for these peaks showed difference for each of the peaks. They reported mean latencies for 1st, Illrd, and Vth peaks as 1.54, 3.73, and 5.52 ms respectively. The first peak latency for less than 6 months group in the present study was found to be 2.19 ms which is comparatively higher (by 0.65 ms) than the adults. This is well supported by literature wherein the prolongation in the 1st peak latency has been reported to be ranging from 0.3 ms (Goldstein, Krumholz, Felix, Shannon, & Carr, 1979; Jacobson, Morehouse & Johnson, 1982) to over 1 ms (Cox, Hack, & Metz, 1981) in comparison to adult values. Also, the difference of 0.20 ms can be observed between the adult norm and the Group B in the present study. This probably shows that Group B had nearly acquired the adult latency value for the first peak. Comparison of Illrd peak latencies between present study and the Antonelli et al. (1987) study was found to be interesting. Both the groups of present study depicted smaller mean latency values (3.47 ms in Group A and 3.30 ms in Group B) when compared to 3.73 ms in the adults as found in

the Antonelli et al. (1987) study. The discrepancy could be attributed to smaller number of subjects in the present study rather than early maturation. Comparison of Vth peak latency showed results more in the expected vein. The mean latencies for Group A and Group B in the present study was found to be 6.50 and 6.08 ms respectively which is higher than the adult value of 5.52 ms (Antonelli et al., 1987). This again indicated that by even 18 months of age, Vth peak did not mature completely.

The comparison of the results between Group A and Group B using Independent t-test produced interesting findings. There was significant difference only for first peak at 90 at 0.05 level of significance ($P<0.01$ and $t=3.74$) and 70 dBnHL at 0.05 level of significance ($P<0.05$ and $t=3.03$) between the two groups. For IIIrd and Vth waves, there was no significant difference between the groups which probably throws light towards a much slower pattern of maturation for these two waves. These observations can be attributed to myelinization of the auditory pathway, the gradual attainment of which would have caused a gradual reduction in conduction time in the auditory nerve and the brainstem structures leading to improvement in latencies with age. The reports in literature suggest that wave I attains adult latency value by 3 months of age, where as waves III and V continue to change until 2-3 years of age, reflecting the caudorostral development pattern (Cox, 1985; Salamy et al., 1980). The findings of present study are, however, partially in agreement with these reports which may be either because of smaller number of subjects in the present study or because of the discrepancy between the age range of the two groups. The latency-intensity function for the two age groups has been shown in the following graph:



GRAPH 1: Latency intensity function of Ist, IIIrd and Vth peaks of ABR and the standard deviation (S.D.).

The lack in number of subjects would contraindicate the generalization of the results to entire pediatric population, rather a more careful usage of these findings is recommended.

For developing the normative value of LLR peak latencies, the subjects were divided into four groups based on their age- 0-6 months (Group a), 7-12 months (Group b), 13-18 months (Group c), and 19-24 months (Group d).

Age group	Peak	Minimum	Maximum	Mean	Standard Deviation (S.D.)
0-6 months	PI	80.00	191.00	137.28 (N=21)	33.51
	Nl	170.00	331.00	219.94 (N= 19)	45.02
	P2	241.00	393.00	317.55(N=20)	56.05
	N2	307.00	473.00	379.33 (N=15)	56.58
7-12 months	PI	85.00	190.00	135.04 (N=24)	27.75
	Nl	147.00	318.00	215.04 (N=24)	39.57
	P2	215.00	377.00	304.25 (N=20)	53.61
	N2	320.00	441.00	370.80 (N=15)	35.35
13-18 months	PI	55.00	170.00	121.82 (N=23)	30.87
	Nl	134.00	306.00	203.00 (N=23)	45.44
	P2	233.00	398.00	291.25 (N=20)	45.64
	N2	334.00	430.00	359.33 (N=12)	31.22
19-24 months	PI	86.00	190.00	118.78 (N=19)	28.18
	Nl	130.00	245.00	182.73 (N= 19)	34.41
	P2	200.00	344.00	257.93 (N=15)	47.55
	N2	307.00	376.00	350.00 (N=08)	25.18

TABLE 11: The mean, Standard deviation (S.D.)? minimum and maximum latencies of LLR peaks (PI, Nl, P2, and N2) at 70 dBnHL across the age groups) (0-6, 7-12,13-18, and 19-24 months).

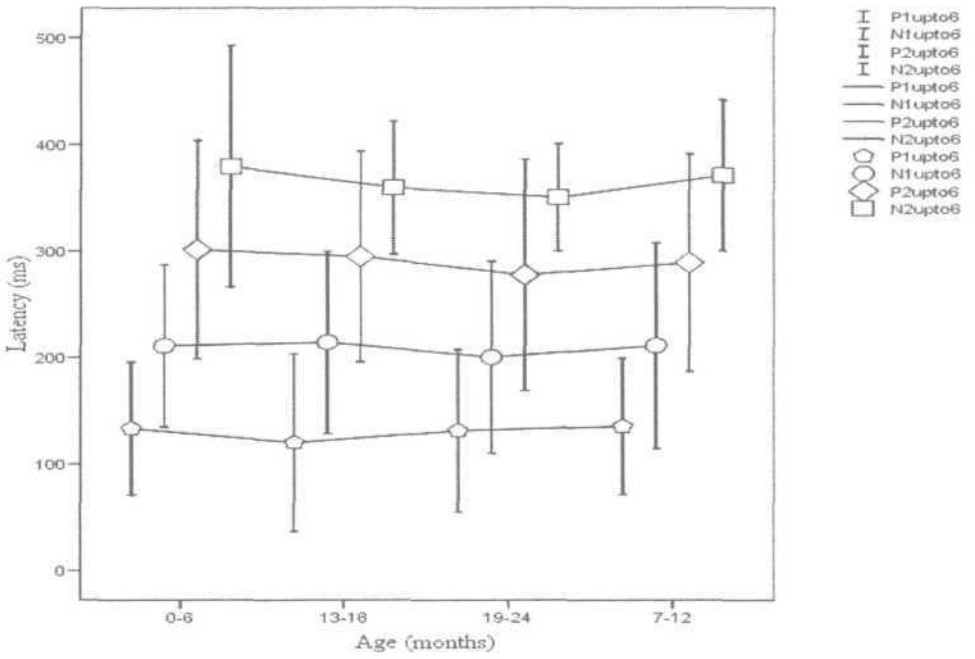
Only those subjects, who did not demonstrate any risk factor, were considered for developing the normative data. The mean reduction in P1, Nl, P2 and N2 latencies from 0-6 months to 19-24 months were 18.50, 37.21, 59.62, and 29.33 respectively. This shows the general trend towards the decrease in latencies with increase in age. PI latency and amplitude change as a function of age (Ceponiene et al., 2002b; Cunningham et al., 2000; Korpilahti, 1996; Ponton et al., 2000, 2002; Sharma et al., 1997). P1 peak latency decreases from about 150 ms in 1-year-old children (Kushnerenko et al., 2002a) to about 100 ms in young and school-aged children (Ceponiene et al., 2002b; Korpilahti, 1996). P2 latency changes from 230 to 150 ms and N2 latency from 535 to 320 ms from 15 days to 3 years of life (Barnet et al., 1975; Ohlrich et al., 1978). Ohlirich et al., (1978) reported a mean reduction in P2 latency of

70-80 ms from 2 weeks to 3 years of age. The mean reduction in latency of Nl over the first 3 years of life was reported to be comparatively less dramatic (about a 10 ms reduction). The present study showed reduction of 59.62 ms and 37.2 ms in P2 and Nl latencies, thus, forms an agreement with the findings of Ohlrich et al., (1978) in terms of pattern of maturation for the two LLR peaks- Nl and P2. It was found that Nl potential showed much lesser reduction latency than P2 in the same age range. All this could be attributed to maturational factors in terms of increase in the myelinization of the cortical neuronal cells. Overall for all LLR peaks, it has been said in literature that latency decreases as a function of increasing age during childhood, up to 10 years, although the most pronounced alterations occur within the first year of life, and to a lesser extent within 2-5 years of age (Akiyama, Schulte, Schultz, & Parmalee, 1969; Ohlrich, Barnet, Weiss, & Shanks, 1978)

The difference in number of ears for each of the peaks is mainly because of lack of presence of all peaks in all of the subjects. Only a handful of subjects showed presence of all peaks. The peak that was least frequently seen was N2 and it could be attributed both to maturational factors and the stage of sleep in which the recording was done. The current study shows that stage of sleep might have significant effect on N2 potential compared to P1, N1, and P2. Report from literature is controversial with regard to N2 potential being endogenous (O'Donnell, Shenton, McCarley, Faux, Smith, Salisbury, Nestor, Pollak, Kikinis, & Jolesz, 1992) or exogenous (Ceponiene, 2001; Naatanen, 1992; Kurzberg et al., 1986). As observed in the present study, the N2 potentials tended to disappear in the subjects who were in deeper sleep stages and were

recordable in those in much lighter sleep stages. This suggests that N2 potential may be endogenous.

The pattern of maturation of all LLR peaks within the first two years of life has been shown in the following graph:



GRAPH 2: Latency of P1, N1, P2, and N2 peaks of LLR across the age groups (0-6, 7-12, 13-18, and 19-24 months). X-axis shows age groups in months and Y-axis shows latency in milliseconds.

So to conclude, it is recommended that the interpretation of LLR wave form should be cautiously approached as large variability across the subjects was encountered in the present study with regard to the latency aspect particularly. It is also

recommended that rather than looking at the latency, it would be better to look for the presence or absence criteria for the diagnosis of different conditions.

Following are the samples of the LLR waveform that were recorded from the subjects of the present study:

FIGURE 4: Presence of PI and Nl component of LLR recorded from a subject of 6 month of age.

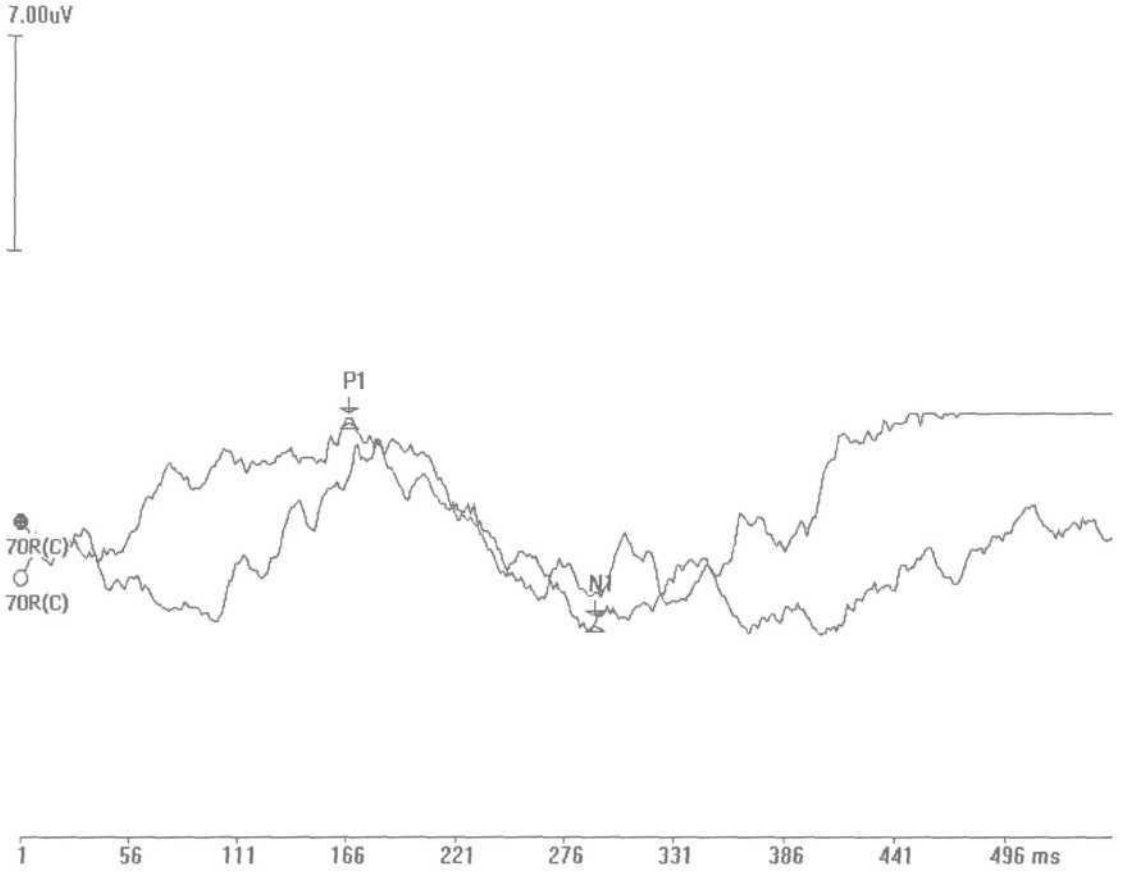


FIGURE 5: presence of P1 and Nl component of LLR recorded from a subject of 16 months of age.

FIGURE 6: Presence of P1, Nl, P2, and N2 components of LLR recorded from a 12 month old subject.

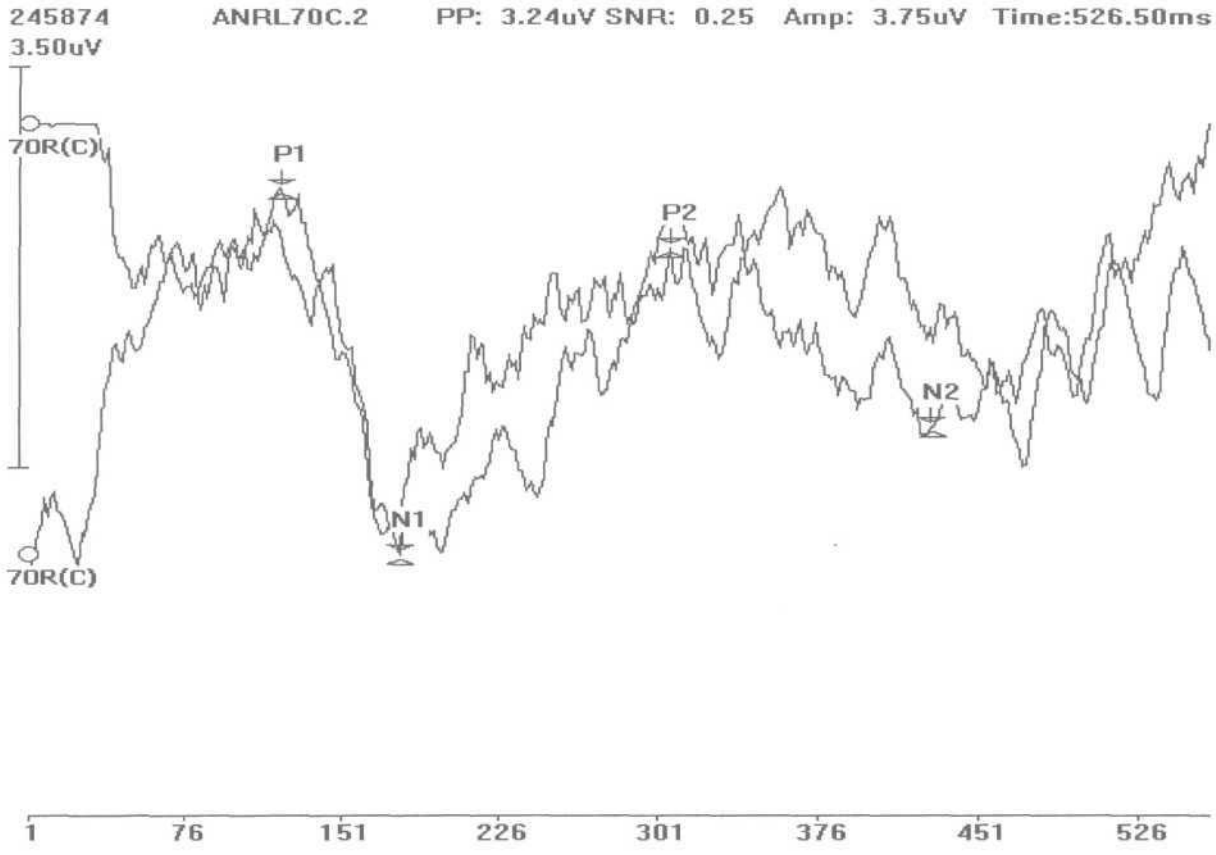


FIGURE 7: Presence of P1, Nl, P2, and N2 components of LLR recorded from an 18 months old subject.

It can be seen from Figures 4 and 5 that only early components of the LLR were present in these subjects. Both these subjects showed absence of N2 which might have the result of their stage of sleep. Both the subjects were in deep sleep when the LLR recording was being done. The components of LLR show high variability in terms of the latency aspect as can be observed from the figures 4 and 5. Similar variation in latency can also be observed from figures 6 and 7. A note was made during recording of the stage (deep or light) of sleep for the subjects which showed that these two subjects were not in deep sleep and this probably might have been the cause of presence of N2 in these subjects. Thus, it is suggested that latency aspect of the LLR components should not be taken into consideration for assessing the maturation of the auditory system in infants and toddlers until and unless a severely prolonged LLR is obtained. It should rather be based on the presence or absence of LLR. A similar criterion should also be implemented for threshold estimation using LLR.

SUMMARY AND CONCLUSION

Hearing is critical for normal speech and language development, which in turn is vital for most aspects of normal human development. A significant hearing impairment at birth can produce major disruption in language learning (Menyuk, 1977) and produce irreversible deficits in the development of central auditory pathways (Moore, 1985). Early identification of hearing loss followed by appropriate management minimizes the auditory deprivation, which can interfere with speech and language learning and central nervous system maturation.

Several investigators (Roberts, Davis, Phon, Reichet, Sturtevants, & Marshall, 1982; Raj, Gupta & Anand, 1991; Galambos & Galambos, 1975) concluded that ABR failures in the infants, in their studies, resulted mainly from immaturity. Infants with risk factors are likely to have varieties of abnormalities in auditory system which might vary from permanent severe hearing loss to normal hearing; reversible audiological test results in Auditory Maturational Delay (AMD) and Auditory Dys-synchrony (AD) of different degrees. An appropriate test protocol is, thus, essential to differentiate one pathological condition from other which will not only implicate in early and appropriate rehabilitation but also provide a sound foundation for parental counseling.

Most authors agree that from 2%-15% of infants with hearing loss may exhibit auditory neuropathy; that is, one can expect to identify auditory neuropathy in approximately 1-3 infants per 10,000 births (Ranee, Beer, Cone-Wesson, Shepard, Dowell, King, Rickards, & Clark, 1999; Sininger, 2002). Numerous researchers' report (Raj, Gupta & Anand, 1991; Berlin, Morlet and Hood, 2003) also cautions clinicians that infants with risk factors have reversible features of auditory dys-synchrony. Thus,

it becomes all the more important for us to be able to differentiate such conditions (AMD) from AD.

McPherson et al. (1989) reported that a fragment of LLR or complete LLR can be obtained in infants even at birth. However, most of the studies using LLR have been carried out in adults and there is very little literature about LLR in infants that focuses on identifying AD. Though the literature on AD in adults suggests that it may not be sensitive to identify AD due to its absence in many of the adults with AD, it still might be a sensitive tool to identify such conditions for infants. It is quite possible that the absence of LLR in adults might have been the result of auditory deprivation caused by inappropriate stimulation of the auditory cortex due pathology at peripheral level. Thus, the present study was taken up with the aim of checking usefulness of LLR in differential diagnosis of Auditory Dys-synchrony (AD) from, its mimicking condition in terms of routine audiological test results, Auditory Maturational Delay (AMD). It was also aimed to develop the normative data for LLR and ABR for infants less than 2 years and 1.5 years of age respectively.

55 infants/ toddlers (30 males and 25 females), with or without risk factors associated with hearing loss, were taken for the study with age below 2 years at the tone of first evaluation. All the subjects were distributed in 4 groups based on then-results of ABR and LLR. Those subjects, who had both ABR and LLR present, were assigned to Group I, where as Group II and III consisted of those subjects who had ABR absent - LLR present and ABR present at least in second or third valuation- LLR absent in first evaluation respectively. The final group, Group IV comprised of those subjects who had neither ABR nor LLR present in any of the recordings. The number

of subjects in Groups I, II, III, and IV, was 18, 14, 10, and 13 respectively. For developing the normative data, only those subjects were considered who did not demonstrate any risk factor associated with hearing loss. For ABR, there were two groups- within 6 months (Group A) and above 6 months (Group B) of age. For LLR, the subjects were divided into 4 groups- up to 6 months (Group a), 7-12 months (Group b), 13-18 months (Group c), and 19-24 months (Group d). The tests administered included BOA, Immittance, OAE, ABR, and LLR.

The results revealed that LLR could be important in differential diagnosis of different conditions that are likely to be encountered when dealing with the hearing assessment of pediatric population of less than 2 years of age.

	BOA	**Immittance**	**OAE**	**ABR**	**LLR**	**Diagnosis**
1.	Normal	A-type	Present	Present	Present	Normal hearing
2.	Normal	A-type	Present	Absent	Present	AD
3.	Normal	A-type	Present	Absent/ Abnormal/ Present	Absent	AMD
4.	Abnormal	A-type	Absent	Absent	Absent	Severe hearing loss

TABLE 12: Different test results and diagnosis based on them.

The test results in case of AMD and AD are identical if LLR results are taken away. The Audiologist will, hence, find it very difficult to diagnose the condition or, more realistically, would have to wait until the maturation has fully occurred. This difficulty can be overcome when LLR results are included. The absence of LLR can be considered for the diagnosis of AMD where as its presence can be termed as AD (based

on the pattern of maturation which suggests peripheral to central course for it) based on presence of ABR at any level and absence of ABR even at high levels respectively. Thus, LLR can prove to be of immense importance in differential diagnosis of AD and AMD. Also, though other routine audiological tests indicate hearing sensitivity within normal limits, still there may be a case of delayed maturation at higher centers (Auditory Cortex). This can be ruled out by presence of LLR. Not only that, LLR can also be used as a substitute for ABR to obtain threshold especially if ABR morphology is poor or if ABR is completely absent as in cases with AD. LLR can also be used as supporting tool for the diagnosis of severe hearing loss. Absence of LLR would indicate minimum or no signal reaching the Auditory Cortex that can evoke a cortical response.

The normative data was also established in the present study for ABR but due to lack in number of subjects, a more careful usage of these findings is recommended. In case of LLR norms, large variability was observed across the subjects. So, it is recommended that the interpretation of LLR wave be cautiously approached especially with regard to the absolute latency. It is also recommended that rather than looking at the latency, it would be better to look for the presence or absence of LLR for the differential diagnosis of different conditions.

Implications of the study:

First and foremost, the study highlights the importance of LLR in differential diagnosis of AMD from AD and permanent hearing loss. So, this brings out a solution to the paradoxical nature of hearing assessment in infants and toddlers.

The study also suggests the use of LLR in threshold estimation especially if there is case of AD in which ABR is absent, and thus implicate in early decision for cochlear implantation and avoid unnecessary psychological trauma to the parents if AMD.

The study also tried to establish norms of ABR and LLR which could be used for arriving at conclusion if an infant or toddler is developing normally or not, though a careful use of the findings of the present study is recommended.

Limitations of the study:

Due to time constraint, sufficient amount of data could not be collected which imposes the limitation at generalization of the results of the study, especially the normative data for ABR.

Though as a conclusion from the study it has been suggested to use LLR for threshold estimation, it would have been better if data regarding this was there to support the suggestion.

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