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Effects of Age, Signal Level, and Signal Rate on the Auditory Middle Latency Response

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Abstract

The effects of age, signal rate, and signal level on the maturing auditory middle latency response (AMLR) were evaluated in 50 normal-hearing subjects ranging in age from 2 days to 35 years. Ipsilateral and contralateral AMLR waveforms were recorded in newborns (n = 10), children (n = 10), preteens (n = 10), teens (n = 10), and adults (n = 10). The AMLR Pa waveform was obtained in 70 to 100 percent of all subjects. The variables of age, signal level, and site of recording significantly affected Pa peak amplitude and absolute latency. However, stimulus rate did not significantly affect the response.

Key Words: Children, evoked potentials, neuroaudiology

Developmental norms for early auditory evoked responses (AERs) such as the auditory brainstem response (ABR) have been well established (Jacobson, 1985; Krumholz et al, 1985). However, controversy exists regarding both the prevalence and clinical application of the auditory middle latency response (AMLR) waveform components (Na, Pa, Pb, Nb) in infants and children. Both subject characteristics and procedural issues that contribute to the difficulty in recording AMLRs in children have been identified. These factors include subject age, signal presentation rate, and level of consciousness.

Table 1 shows 23 pediatric AMLR studies published between 1971 and 1989. The majority of pediatric AMLR papers published before 1982 reported that the AMLR could be consistently recorded in infants and young children. However, these AMLR recordings were obtained using very narrow filter settings, that is between 25 and 125 Hz. Scherg (1982) identified distortions in the pediatric AMLR waveform caused by the use of narrow filter settings. The distortions created by steep filtering were due to artifact that was introduced into the recording. This caused the emergence of nonphysiologic peaks in the waveform (McGee et al, 1988) or additional energy creating a much larger middle component than was present physiologically. The results concerning the presence of the AMLR waveform in children from studies published after 1982 using wider filter settings are conflicting.

A landmark study (Kraus et al, 1985) reported the significant effects of age on the prevalence of AMLR waveforms recorded in children. Kraus et al found that AMLR waveform (Na and Pa) were not present in all normal subjects tested until 10 years of age. However, these neurologically normal children (n = 33) were asleep and sedated during the AMLR testing procedure. Kraus et al (1989) later reported that the subject's level of consciousness played an important role in AMLR waveform (Pa) consistency. They suggest that the AMLR waveform can be successfully recorded in young children only during certain stages of sleep or during wakefulness. Table 1 lists the sleep state of the subjects when the AMLR recordings were obtained. This table shows that the majority of these pediatric AMLR studies recorded AMLRs in sleeping or sedated subjects.

Stimulus rate was shown to have a significant effect on recording AMLR waveforms in young children. In two studies (Fifer et al, 1984; Jerger et al, 1987), infant AMLR recordings

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Table 1 Pediatric AMLR Studies

Study	*N*	*Subject Age*	*Intensity*	*Sleep State*	*Consistent MLR*
Engel, 1971	14	Newborn	72 dB SPL	Asleep	No
McRandle et al, 1974	10	Newborn	55 dB HL	Asleep	Yes
Mendel et al, 1977	18	1, 4, 8 mo	15, 30, 45, 60 dB HL	Asleep	Yes
Wolf and Goldstein, 1978	5	Newborn	10, 30, 50 dB HL	Asleep	Yes
Frye-Osier and Reed, 1980	20	Newborn	20, 40, 60 dB HL	Asleep	Yes
Frye-Osier and Hirsch, 1980	20	Newborn	50 dB nHL	Asleep	Yes
Mendelson and Salamy, 1981	60	Premature baby to adult	60 dB nHL	Asleep/awake	Yes
Frye-Osier et al, 1982	18	Newborn	20, 40, 60 dB nHL	Asleep	Yes
Suzuki et al, 1983	26	1–7 yr	60 dB nHL	Sedated	Yes
Kileny and Berry, 1983	15	6 wk–15 yr	60, 70 dB nHL	Unknown	Yes
Suzuki and Kobayashi, 1984	17	Newborns–36 yr	70, 80 dB nHL	Sedated	Yes
Okitsu, 1984	29	4 mo–3 yr	30, 40, 50 dB nHL	Asleep	No
Fifer et al, 1984	12	26–46 wk	70 dB nHL	Asleep	Yes
Mason and Mellor, 1984	18	7–12 yr	70 dB HL	Awake	Yes
Lynn et al, 1984	32	0–6 yr	Variable	Unknown	No
Kraus et al, 1985	33	0–20 yr	60, 70 dB HL	Sedated	No
Woods and Clayworth, 1986	24	20–80 yr	50, 60 dB HL	Unknown	Yes
Jerger et al, 1987	8	2–6 mo	60 dB nHL	Asleep	Yes
Stapells et al, 1988	26	3 wk and adult	70 dB nHL	Asleep/awake	No
Kavanaugh et al, 1988	48	0–13 mo	30 dB nHL	Unknown	No
Barajas et al, 1988	17	5–12 yr	0–25 dB nHL	Asleep/awake	Yes
McPherson et al, 1989	28	Newborn and adult	40 dB above ABR threshold	Asleep/awake	Yes
Kraus et al, 1989	6	4–9 yr	50 dB nHL	Asleep	Yes

appear to be enhanced using a signal rate below 5 per second. The use of a signal rate above 5 per second caused reductions in the amplitude of AMLR waveforms or resulted in the absence of AMLR waveform components. There is a paucity of data on the effect of stimulus rate on the AMLR Pa waveform in children, preteens, or teens.

The effect of signal intensity on pediatric AMLR testing has not been thoroughly investigated. As can be seen in Table 1, only 7 of 23 studies cited used a signal level of 70 dB nHL or greater to obtain an AMLR recording in children. Given that Wolf and Goldstein (1978) found that AMLR waveform amplitude increased as stimulus magnitude increased in newborns, it is surprising that researchers have not used higher signal levels when determining the presence or absence of an AMLR Pa waveform in infants or small children. A test strategy employing several high signal levels is often used clinically in ABR neuroaudiologic testing when trying to optimize the ABR.

The purpose of this study was to investigate the effect of both subject and parametric factors on the maturing AMLR Pa waveform. In terms of parametric factors, this study compared the effects of signal level and signal rate on the maturing AMLR waveform. The subject factor of age was investigated by obtaining developmental AMLR data on awake subjects in children, preteens, teens, and adults. In addition, the effects of signal level and signal rate were studied in a group of newborns. With the newborns, AMLRs could only be obtained during a natural sleep state. Since it has been reported that sleep state can have a significant effect on recording AMLRs in children (Kraus and McGee, 1989) and that monitoring sleep states in infants through electroencephalography (EEG) is extremely difficult to interpret (Ellingson, 1975), sequential patterns of AMLR development between the infants and the children could not be determined in the context of the present study. However, the infant AMLR data is reported here as representative of AMLR recordings typically obtained from sleeping infants.

METHOD

Subjects

Fifty subjects with normal hearing sensitivity were studied. Adult, teen, preteen, and child subjects were assessed with an otoscopic exam, tympanometry, and pure-tone and speech audiometry prior to the AMLR procedure. Criteria for normal hearing sensitivity for these subjects included pure-tone thresholds for frequencies 250 to 8000 Hz of 15 dB HL or better, speech reception thresholds (SRTs) of 15 dB HL or better, and tympanometry with a peak between –100 to +100 daPa of pressure.

Hearing sensitivity was assessed in infants with an ABR screening procedure. Infants showing an ABR wave V within a normal age-appropriate range were admitted to the study. A 20 dB nHL click stimulus was used in the infant ABR testing.

The experimental design included five age groups (n = 10): infants (2 days old), children (5–7 years old), preteens (9–12 years old), teens (13–16 years old), and adults (18–35 years old). Since the subject must remain very still and relaxed during the AMLR testing procedure, it is usually necessary to test young children during natural or sedated sleep. We were determined, however, not to use sedatives in this study. Therefore, children between the ages of 1 to 4 years were excluded.

Adult EEG sleep patterns, characterized by four stages of slow wave sleep and a period of active sleep called rapid eye movement (REM), appear in children at 8 years of age (Ellingson, 1975). For this reason, 8-year-old children were excluded from the study. Consequently, the two youngest subject groups were children (ages 5 to 7 years) and preteens (9 to 12 years). These subject groups were selected to investigate the amount of change in the AMLR before and after this critical maturation stage of EEG sleep pattern occurring in children at 8 years of age.

Procedures

Infants. The newborns were tested in their infant cribs in the University of Virginia East Hospital's well-baby nursery. The ambient noise levels in the newborn nursery were measured with a Bruel and Kjaer sound level meter (model #2231). Ambient noise levels measured in the newborn nursery varied around 51 dBA. During the AMLR procedure, infants were placed lying on one side in their infant cribs.

Adults, Teens, Preteens, and Children. These subjects were tested in the University of Virginia (UVA) Audiology Satellite Suite in the East Hospital. Wideband noise measurement in the sound suite was 33 dBA. Subjects were required to lie still in a supine position in a comfortable easy chair in the sound suite du ing the evoked potential testing.

Evoked Response Acquisition

The Nicolet Compact Four (C-4) electrodiagnostic system was used to generate the click stimulus and to acquire the evoked response. Post hoc analysis of the AMLR waveform latency and amplitudes was performed on the Nicolet Pathfinder II electrodiagnostic system.

Skin surfaces on the subject's scalp were cleaned with Omni Prep Solution, a mild abrasive solution, and then with a normal saline solution. Gold cup EEG electrodes were attached to the skin with EC2 electrode cream, gauze pads, and tape. Electrodes were placed on the following locations: (1) noninverting electrode on the vertex (Cz); (2) inverting electrodes on the earlobes (A1 and A2); and (3) ground electrode on the forehead (Fpz). Measured interelectrode impedance was kept below 5000 ohms and balanced to within 1500 ohms between electrode pairs. Scalp neuroelectric activity was amplified (100,000×) and then filtered with C-4 analog filters (10 Hz high pass and 1000 Hz low pass/ 12 dB per octave filter roll-off). Raw EEG activity was averaged over an 80-msec time base immediately following stimulus onset. Raw evoked response data were stored on individual floppy disks, to be analyzed later on the Pathfinder II system.

AMLR Response Parameters

The subjects were presented with four sets of rarefaction click stimuli through a Nicolet C4 ER-3A 300-ohm insert transducer. A Nicolet disposable 10-mm polyurethane foam eartip was placed in the subject's ear for stimulus delivery. All signals were presented to the subject's right ear at two signal levels, 70 dB nHL and 40 dB nHL. At each signal level, AMLR were obtained for signal rates of 3.3/second and 11.3/second. A two-channel recording (ipsilateral and contralateral) was obtained for each AMLR waveform. Two waveforms were recorded for each signal rate and signal intensity to show replicability. A total of 2000 sweeps was recorded in each AMLR waveform.

Data Analysis

Peak-to-peak amplitudes (μV) and absolute latencies (msec) of the AMLR Pa waveform measures for each pair of replicated waveforms in each subject were averaged, and a mean value was used for statistical analysis. Peak-to-peak amplitude for the Pa waveform was measured from the bottom of the preceding Na trough to the top (highest point) on the Pa waveform. Latency was measured to the highest point on the Pa waveform. Descriptive and inferential statistical methods were used to analyze data. Regression and multivariate analyses of variance (MANOVA) were performed. Post hoc Tukey tests were done after trend analysis to determine which age groups differed significantly. Means and standard deviations of the AMLR Pa waveforms for each of the age groups were obtained for the different stimulus conditions. For waveform latency, an absent response was not calculated into the numeric analysis (as a zero). For peak waveform amplitude, an absent response (essentially a straight line) does have a true meaningful zero value, and an absent response (a zero) was included in group mean data. In this study, the alpha level was set at 0.05 in all statistical calculations.

RESULTS

Effect of Age

The prevalence of recorded Pa waveforms is found in Table 2. The AMLR Pa was observed 100 percent of the time in all stimulus conditions in teen and adult subjects. In the 70 dB nHL condition, the Pa waveform was observed in all subjects for the ipsilateral recording. For the contralateral 70 dB nHL condition and in the ipsilateral and contralateral 40 dB nHL conditions, the prevalence of the AMLR Pa waveform varied across age groups, ranging from 70 percent in infants to 100 percent in adults.

Table 3 shows the latency values for the Pa waveforms. In all stimulus conditions, Pa response latency was longest in the infant groups and became progressively shorter as a function of age in the other subject groups. Contralateral recordings were longer in latency than ipsilateral recordings for all age groups except children. Ipsilateral and contralateral latencies varied for the children. Standard deviations were largest for the newborns and progressively decreased among the other subject groups as a function of age.

The numeric values of Pa peak amplitudes for the different stimulus conditions are listed in Table 4. With the exception of the contralateral 40 dB nHL/11.3 per second presentation rate condition, Pa response amplitudes were smallest for infants, increasing in amplitude through the teens and decreasing in amplitude in the adults. Pa response amplitudes were varied for the contralateral 40 dB nHL/11.3 per second presentation rate condition. The ipsilateral recordings were larger in amplitude than contralateral recordings in all stimulus conditions for all subjects.

Two unusually large standard deviations are listed in Table 4. One is the newborn contralateral 40 dB HL/11.3 second amplitude and the other is the teen contralateral 70 dB HL/11.3 second amplitude. In the newborn tracings,

Table 2 Prevalence of Pa Waveform

Rate	Site	Newborn	Child	Preteen	Teen	Adult
70 dB nHL Signal Level Recordings (%)						
3.3/sec	Ipsilateral	100	100	100	100	100
	Contralateral	70	80	90	100	100
11.3/sec	Ipsilateral	100	100	100	100	100
	Contralateral	70	80	90	100	100
40 dB nHL Signal Level Recordings (%)						
3.3/sec	Ipsilateral	90	80	90	100	100
	Contralateral	70	80	90	100	100
11.3/sec	Ipsilateral	90	80	90	100	100
	Contralateral	70	80	90	100	100

Table 3 AMLR Pa Mean Latencies and Standard Deviations in Msec

Condition (SD)	Newborn	Child	Preteen	Teen	Adult
Ipsilateral Recordings					
70 dB/3.3/sec	36.34	28.78	28.24	29.31	27.66
	5.26	4.96	3.54	3.79	2.11
70 dB/11.3/sec	35.98	30.28	28.04	27.69	27.44
	8.38	3.32	3.86	3.52	2.05
40 dB/3.3/sec	36.56	30.59	29.60	29.72	29.42
	5.94	6.05	3.74	2.70	3.16
40 dB/11.3/sec	35.52	31.30	28.84	29.87	28.91
	4.74	3.40	3.23	3.73	2.19
Contralateral Recordings					
70 dB/3.3/sec	38.40	29.50	28.91	29.89	29.19
	3.54	5.65	4.36	3.37	2.16
70 dB/11.3/sec	37.50	29.80	29.15	27.98	27.99
	6.37	5.07	4.10	3.61	1.82
40 dB/3.3/sec	37.23	32.07	29.70	30.20	29.95
	3.15	6.66	3.61	2.55	2.70
40 dB/11.3/sec	39.90	30.54	29.28	30.57	29.07
	4.10	3.15	3.40	2.83	2.30

there were cases where newborn contralateral tracings were absent, as reflected in the prevalence values found in Table 2. These zero values created the standard deviation that is almost as large as the mean. In the teen recordings, there was a single subject who had extremely large Pa amplitudes (4.4 μV). His large Pa amplitudes inflated the standard deviation score.

The morphology of the AMLR waveforms changes with age. AMLR tracings, found in Figures 1 and 2, show the infant AMLR tracing to be very broad. The Nb peak, a negative trough following the Pa positive peak, appears to be absent. In some instances, the infant response is so broad and small in amplitude that it is necessary to rescale the data to better identify

Table 4 AMLR Pa Mean Amplitudes and Standard Deviations in Msec

Condition (SD)	Newborn	Child	Preteen	Teen	Adult
Ipsilateral Recordings					
70 dB/3.3/sec	.77	.99	1.36	1.33	1.22
	.22	.42	.53	.73	.35
70 dB/11.3/sec	.80	1.00	1.31	1.30	1.14
	.22	.49	.54	1.20	.39
40 dB/3.3/sec	.54	.69	.85	.80	.81
	.32	.43	.39	.38	.30
40 dB/11.3/sec	.45	.57	.91	.84	.80
	.21	.38	.21	.49	.39
Contralateral Recordings					
70 dB/3.3/sec	.65	.95	1.08	1.13	1.07
	.26	.32	.27	.63	.26
70 dB/11.3/sec	.56	.87	1.17	1.30	1.09
	.24	.44	.48	1.19	.33
40 dB/3.3/sec	.39	.55	.69	.69	.82
	.29	.44	.73	.31	.21
40 dB/11.3/sec	.28	.44	.73	.63	.74
	.22	.30	.26	.29	.30

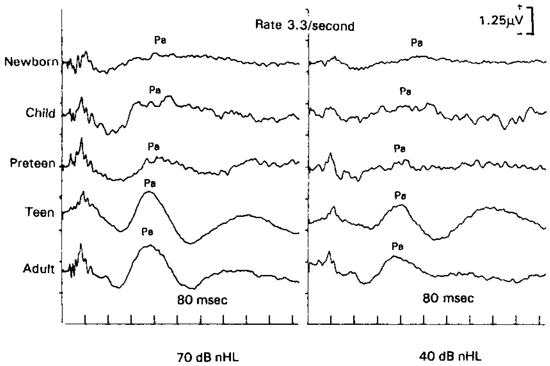

Figure 1 Sample AMLR tracings for five age group subjects using a high 70 dB nHL and low 40 dB nHL signal level stimulus. These recordings were obtained using a 3.3/second stimulus presentation rate.

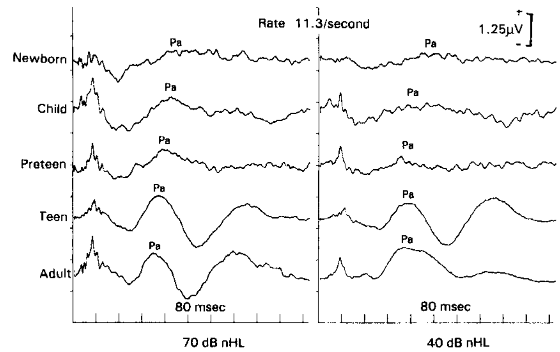

Figure 2 Sample AMLR tracings for five age group subjects using a high 70 dB nHL and low 40 dB nHL signal level stimulus. These recordings were obtained using an 11.3/second stimulus presentation rate.

the Pa waveform. Increasing the display gain was used to help measure Pa peak amplitude and latency.

The child and preteen AMLR begins to show a larger Pa peak with a more defined Nb peak following the Pa waveform. The teen and the adult AMLR shows a well-defined Pa waveform.

MANOVA was done to determine if age had a significant effect on Pa peak amplitudes and absolute latencies. The effect of age was significant on ipsilateral Pa latency ($F = 7.25$, $p = .0001$), contralateral Pa latency ($F = 5.37$, $p = .02$), ipsilateral peak amplitude ($F = 2.88$, $p = .03$), and contralateral peak amplitude ($F = 4.27$, $p = .005$).

Effect of Signal Level

Figures 1 and 2 show examples of AMLR recordings obtained for one subject in each age group at the two signal levels (40 dB nHL and 70 dB nHL). For each signal rate, the AMLR recordings show a decrease in Pa peak amplitude when the lower 40 dB nHL signal level was used. Numeric values in Table 4 also show Pa peak amplitudes to be smaller at the 40 dB nHL signal level for both ipsilateral and contralateral recordings. MANOVA showed that the effect of signal level was significant on ipsilateral Pa latency ($F = 4.72$, $p = .03$), contralateral Pa latency ($F = 5.37$, $p = .02$), ipsilateral Pa peak amplitude ($F = 35.42$, $p = .0001$), and contralateral Pa peak amplitude ($F = 38.51$, $p = .0001$). There did not appear to be a significant age × signal level interaction for ipsilateral Pa latency ($F = .40$, $p = .808$), contralateral Pa latency ($F = .39$, $p = .815$), ipsilateral amplitude ($F = .38$, $p = .823$), or contralateral amplitude ($F = .65$, $p = .511$).

Regression analysis showed linear and quadratic trends in ipsilateral Pa latency in all stimulus conditions, with the exception of the 70 dB nHL/11.3 per second signal. A cubic trend was observed in this condition. A post hoc analysis (Tukey) revealed that newborns differed significantly from other groups for ipsilateral Pa latency values in all stimulus conditions.

Statistical analysis showed significant linear and quadratic trends in all stimulus conditions for the contralateral Pa latency, and post hoc Tukey analysis revealed that newborns differed significantly from all other age groups in all stimulus conditions, with the exception of the 40 dB nHL signal level/3.3 per second rate condition. In this condition, contralateral AMLR Pa waveform latency in newborns differed significantly from the three older groups.

Regression analysis was done on the Pa amplitude data to test for significant trends. No uniform pattern of linear trend was seen in ipsilateral Pa amplitudes. A significant linear trend was seen in two stimulus conditions (high signal level/slow click rate and low signal level/fast click rate), while quadratic trends were seen in all stimulus conditions except the low signal level/slow click rate condition. No cubic trends were seen in the ipsilateral Pa mean amplitudes. Post hoc analysis (Tukey) indicated that none of the age groups significantly differed from one another.

Trend analysis done on contralateral Pa amplitude data revealed linear trends in all stimulus conditions and quadratic trends in all conditions except the low signal level/slow click rate condition. No significant cubic trends were observed. In both of the 40 dB nHL conditions, post hoc Tukey tests indicated that the newborns differed significantly from the adult groups.

Effect of Rate

The effect of signal rate was not significant for ipsilateral Pa latency ($F = .53$, $p = .47$), contralateral Pa latency ($F = 1.34$, $p = .254$), ipsilateral Pa amplitude ($F = .18$, $p = .672$), or contralateral Pa amplitude ($F = .31$, $p = .579$). There was no significant age $\times$ rate interaction for ipsilateral Pa latency ($F = 1.24$, $p = .309$), contralateral Pa latency ($F = .74$, $p = .57$), ipsilateral Pa amplitude ($F = .14$, $p = .964$), or contralateral Pa amplitude ($F = .83$, $p = .511$).

DISCUSSION

Effect of Age

The AMLR Pa was observed consistently in teen and adult subjects. This observation agrees with the findings reported by Kraus et al (1985). However, the prevalence of observed Pa responses in infants and children was higher in the present study than in the study by Kraus et al (1985). These investigators reported the prevalence of AMLRs to be approximately 20 percent for newborns, 35 percent for 5-year-old children, and 72 percent for 11-year-old preteens. In the present study, the prevalence of AMLRs was 70 to 100 percent for subjects ranging in age from 2 days to 35 years.

These differences may be due to three possibilities. First, all subjects in the Kraus et al (1985) study were asleep and sedated with 25–50 mg/kg chloral hydrate whereas all subjects in this study, with the exception of newborns, were required to remain awake during the AMLR assessment.

Second, in the earlier study by Kraus et al (1985), normative data were based on 33 subjects in six age groups, ranging in age from birth to 20 years. The number of subjects in each age group was, on average, 5 to 6. The present study recorded AMLRs in 50 normal-hearing subjects in five age groups; consequently, there were 10 subjects per age group.

Third, Kraus et al (1985) used earphones mounted in cushions for stimulus delivery. In the present study, insert transducers were used. Insert transducers would be less likely to cause ear canals to collapse during testing of small infants and young children.

The AMLR Pa latencies decreased with increasing age. Mendel et al (1977) also found that AMLR latencies decreased with an increase in subject age. In the present study, AMLR Pa waveform peak-to-peak amplitudes increased as a function of age from childhood through adolescence while AMLR Pa waveform peak-to-peak amplitudes decreased as a function of age in adulthood. This pattern of maturation is similar to that reported for cortical P300 auditory evoked response (Goodin et al, 1978). This may be due to the cortical generators underlying the Pa response (Kraus et al, 1987, 1988; Jacobson and Newman, 1990).

The results of this study indicate the AMLR to be a dynamic response, continually changing in latency and amplitude through adulthood. Studies reviewed in Table 1 show that a majority of pediatric AMLR research has focused on newborns and small children. However, only four of these studies included subjects between 9 to 12 years (Kileny and Berry, 1983; Mason and Mellor, 1984; Kraus et al, 1985; Barajas et al, 1988) and only two studies included subjects between 13 to 16 years (Kileny and Berry, 1983; Kraus et al, 1985). Further research is needed to examine the changes occurring in the AMLR in older children and teenagers.

Effect of Intensity

Wolf and Goldstein (1978) reported that the AMLR latency decreased and amplitude increased as stimulus magnitude was increased. Results of the present study support this finding. The literature reviewed in Table 1 found only six studies using a signal level of 70 dB HL or 70 dB nHL and higher (Engel, 1971; Kileny and Berry, 1983; Fifer et al, 1984; Suzuki and Kobayashi, 1984; Mason and Mellor, 1984; Kraus et al, 1985; Stapells et al, 1988). The use of lower signal levels is surprising given the implied linear relationship between the magnitude of the acoustic stimulus and the magnitude of the recorded response. Just as a high-intensity signal level is needed when assessing neurophysiologic function with an ABR evaluation, a sufficiently intense signal level (70 dB HL or greater) may be necessary in order to record an optimal AMLR in infants and small children.

Effect of Rate

The investigators did not find that stimulus rate had a significant effect on the AMLR recording. However, the absence of a significant rate effect does not agree with the findings of Fifer et al (1984) or Jerger et al (1987).

Effect of Recording Site

Ipsilateral and contralateral recordings were obtained from each stimulus presentation. Previous research in the development of the ABR has shown that the contralateral response does not develop on the same time course as the ipsilateral response (Edwards et al, 1985). We expected to see differences in the maturation of contralateral responses in the AMLR. These differences were apparent in the lower prevalence of contralateral AMLR in infants, as shown in Table 2.

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